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Section 5

Inspection and Evaluation of Decks

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Topic 5.1 Timber Decks

5.1.1 Introduction

Timber bridges make up approximately 7% of the bridges listed in the National Bridge Inventory (NBI). Furthermore, approximately 7% of the steel bridges, which are categorized as steel bridges in the NBI also have timber decks. Timber can be desirable for use as a bridge decking material because it is resistant to deicing agents, which typically harm concrete and steel, and it is a renewable source of material. Timber can also withstand relatively larger loads over a short period of time when compared to other bridge materials. Finally, timber is easy to fabricate in any weather condition and is lightweight.

5.1.2 Design Characteristics

Timber decks are normally referred to as decking or timber flooring, and the term is generally limited to the roadway portion which receives vehicular loads. Timber decks are usually non-composite because of the inefficient shear transfer through the attachment devices. The basic types of timber decks are:

- Plank decks
- Nailed laminated decks
- Glued-laminated deck panels
- Stressed-laminated decks
- Structural composite lumber decks

Plank Decks

Plank decks consist of timber planks laid transversely across the bridge (see Figure 5.1.1). The planks are individually attached to the bridge beams using spikes or bolt clamps, depending on the beam material. It is common for plank decks to have 50 mm (2-inch) depth timbers nailed longitudinally on top of the planks to distribute load and retain the bituminous wearing surface.

Figure 5.1.1 Plank Deck

Nailed Laminated Decks

Nailed laminated decks consist of timber planks with the wide dimensions of the planks in the vertical position and laminated by through-nailing to the adjacent planks (see Figure 5.1.2). On timber beams, each lamination is toenailed to the beam. On steel beams, clamp bolts are used as required. In either case, laminates are generally perpendicular to the roadway centerline.

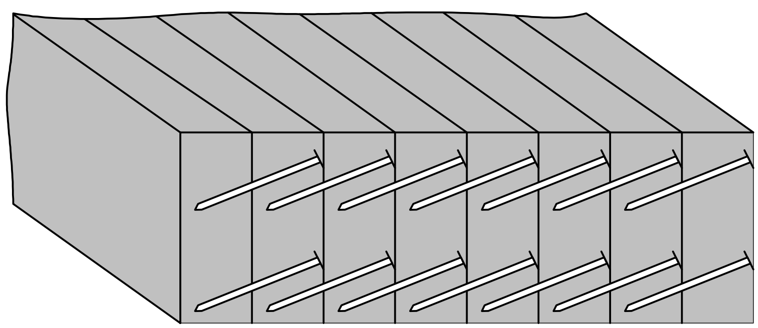

Figure 5.1.2 Section of a Nailed Laminated Deck

Glued-laminated Deck Panels

Glulam is an engineered wood product in which pieces of sawn lumber are glued together with waterproof adhesives. Glued laminated deck panels come in sizes usually 1.2 m (4 feet) wide. The panels are laid transverse to the traffic and are attached to the superstructure. In some applications, the panels are interconnected with dowels. There are several techniques used to attach glued-laminated decks to the superstructure or a floor system, including nailing, bolting, reverse bolting, clip angles and bolts, and nailers (see Figure 5.1.3).

The nailing method is generally not preferred due to the possibility of the nails being pried loose by the vehicle traffic.

Bolting the deck to the superstructure or floor system provides a greater resistance to uplift than nailing, but bolts may still be pried loose.

Reverse bolting involves fastening the bolts to the underside of the deck on either side of the stringers, thereby preventing the lateral movement of the deck. This is a rare type of connection.

Clip angles and bolts involve attaching clip angles to the stringers and then using bolts to attach the clip angles to the deck.

Nailers are planks that run along the top of steel stringers. This technique involves the bolting of the nailers to the stringers and nailing the timber planks to the nailers. This prevents the costly bolting of all planks to the steel stringers.

Figure 5.1.3 Glued-laminated Deck Panels

Stressed-laminated Decks

Stressed-laminated decks are constructed of sawn lumber glulam wood post-tensioned transversely utilizing high strength steel bars. Stressed timber decks consist of thick, laminated timber planks which usually run longitudinally in the direction of the bridge span. The timber planks vary in length and size. The laminations are squeezed together by prestressing (post-tensioning) high strength steel bars, spaced approximately 600 mm (24 inches) on center. With a hydraulic jacking system tensioning the bars, they are passed through predrilled holes in the laminations. Steel channel bulkheads or anchorage plates are then used to anchor the prestressing bars. This prestressing operation creates friction connections between the laminations, thereby enabling the laminated planks to span longer distances (see Figure 5.1.4).

Prestressed laminated decks are used on a variety of bridge superstructures, such as trusses and multi-beam bridges, and they can be used as the superstructure itself for shorter span bridges.

Figure 5.1.4 Stressed-laminated Deck

Structural Composite Lumber Decks

Structural composite lumber (SCL) decks include laminated veneer lumber (LVL) and parallel strand lumber (PSL). Laminated veneer lumber is made by gluing together thin sheets of rotary-peeled wood veneer with a waterproof adhesive. Parallel strand lumber is made by taking narrow strips of veneer and compressing and gluing them together with the wood grain parallel. SCL bridge decks are gaining popularity and are comprised of a parallel series of fully laminated LVL or PSL T-beams or a parallel series of fully laminated LVL or PSL box beams. The T-beams and box sections run parallel with the direction of traffic and are cambered to meet the needs of the specific bridge site. The box sections or T-beams are stress laminated together by either placing steel bars or prestressing strands through the top flanges (timber deck area) and/or through the outside edges of the box section top flanges. Steel channels or bearing plates are then placed on the bars or strands with double nuts. Standard strand chucks are placed on the opposite end to initiate the prestressing process. The prestressing bars or strands are generally epoxy coated to resist corrosion.

Structural composite lumber decks are capable of full preservative penetration, and asphalt overlays are typical.

Figure 5.1.5 Structural Composite Lumber Deck Using Box Sections

5.1.3 Wearing Surfaces

The wearing surface of a timber deck is constructed of either timber, bituminous materials, or concrete. Timber wearing surfaces usually run parallel with traffic and are used with transverse plank decks. Bituminous wearing surfaces can either be hot mix asphalt or a chip and seal method. Concrete wearing surfaces for timber decks are less common than timber or bituminous wearing surfaces, although some exist.

Timber

A timber wearing surface may consist of longitudinal timbers placed over the transverse decking. Runner planks or "running boards" are planks placed longitudinally only in the strips where the wheels of vehicles ride (see Figure 5.1. 6).

Figure 5.1.6 Timber Wearing Surface on a Timber Deck

Bituminous

Bituminous or asphalt wearing surfaces generally consist of a coarse aggregate. The aggregate is mixed with a binder substance that holds the aggregate together and bonds the surfacing to the deck. Asphalt is a popular bituminous wearing surface for timber decks. However, it is not commonly used on plank decks due to the fact that deflection of the planks will cause the asphalt to break apart.

Concrete

While concrete may be used as a wearing surface on timber decks, it is not frequently used for this purpose. However, new composite studies between concrete overlays and timber decks are being performed. These studies generally involve a timber deck with steel shear studs doweled into the timber deck with a concrete overlay completing the composite action.

5.1.4 Protective Systems

Protective systems are necessary to resist decay in timber bridge decks. Water repellents, preservatives, fumigants, fire retardants, and paints are some of the common timber protective materials. In order for the protective material to serve its purpose, the surface of the timber must be properly prepared.

Water Repellents

Water repellents help to prevent water absorption in timber decks, which slows decay by molds and weathering. The amount of water in wood directly affects the amount of expansion and contraction due to temperature. Water repellents are used to lower the water content of timber deck members and must be reapplied periodically. Because it needs to be applied rather frequently, it is not the best means of protecting timber structures.

Preservatives

Timber preservatives are usually applied by pressure, which forces the preservative into the timber deck member. The deeper the preservative penetration, the greater the protection from decay by fungi. Preservatives are the best way to protect against decay.

Preservatives are either oil-based or water-based. Some common oil-based preservatives are coal-tar creosote and pentachlorophenol. Chromated copper arsenate (CCA) is a very common water-based preservative.

Fumigants

Fumigants are applied to timber members in a liquid form through drilled holes. Once in the hole, the hole is plugged and the fumigant volatilizes and moves through the member as a gas, thus preserving the internal heartwood. Two common types of fumigants are chloropicrin and metham. These two fumigants are very hazardous and can only be applied by a professional. Also, the locations in which these fumigants can be applied are limited.

Fire Retardants

Fire retardants slow the spread of fire and prolong the time required to ignite the wood. The two main types of fire retardants are pressure impregnated salts and intumescent paints. These retardants insulate the wood, but adversely affect the material properties of wood.

Paint

Paints for timber decks can either be oil-based, oil-alkyd or latex-based. Oil-based paints provide the best barrier from moisture but is not very durable. Oil-alkyd paints have more durability than oil-based paints but contain lead pigments which cause various health hazards. Latex-based paints, on the other hand, are very flexible and resistant to chemicals.

5.1.5

Overview of Common Defects

A prepared bridge inspector should know what to look for prior to the inspection. The following is a list of common defects that may be encountered when inspecting timber bridge decks. Refer to Topic 2.1 for a detailed description of these common defects:

- Fungus decay
- Damage by parasites
- Deflection
- Checks
- Splits
- Shakes
- Loose connections
- Surface depressions
- Chemical attack

5.1.6 Inspection Procedures and Locations

Procedures

Visual

The inspection of timber decks for deterioration and decay is primarily a visual activity. All surfaces of the deck planks should receive a close visual inspection.

Physical

However, physical examinations must also be used for suspect areas. The most common physical inspection techniques for timber include sounding, probing, drilling, core sampling, and electrical testing. An inspection hammer should be used initially to evaluate the subsurface condition of the planks and the tightness of the fasteners. In suspect areas, probing can be used to reveal decayed planks using a pick test or penetration test (see Figure 5.1.7). A pick test involves lifting a small sliver of wood with a pick or pocketknife and observing whether or not it splinters or breaks abruptly. Sound wood splinters, while decayed wood breaks abruptly. If the deck planks are over 50 mm (2 inches) thick, suspect planks should be drilled to determine the extent of decay.

Figure 5.1.7 Inspector Probing Timber with an Ice Pick at Reflective Cracks in the Asphalt Wearing Surface

Advanced Inspection Techniques

In addition, several advanced techniques are available for timber inspection. Nondestructive methods, described in Topic 13.1.2, include:

- Pol-Tek
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 13.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Shigometer

Locations

Timber deck inspection generally includes visually interpreting the degree of decay on the top and, if visible, the bottom and sides of the deck. Also, all visible fastening devices and bearing areas should be inspected. In all instances, it is helpful if the inspector has available the previous inspection report so that the progression of any deterioration can be noted. This provides a more meaningful inspection.

The primary locations for timber deck inspection include:

- **Areas exposed to traffic** - examine for wear, weathering, and impact damage (see Figure 5.1.8)
- **Bearing and shear areas** where the timber deck contacts the supporting floor system - inspect for crushing, decay, and fastener deficiencies (see Figure 5.1.9)
- **Tension areas** between the support points - investigate for flexure damage, such as splitting, sagging, and cracks
- **Deck surface** - check for decay, particularly in areas exposed to drainage (see Figure 5.1.10)
- **Outside edges of deck** - inspect for decay
- **Nailed laminated decks** - swelling and shrinking from wetting and drying cause a gradual loosening of the nails, displacing the laminations; this permits moisture to penetrate the deck and superstructure, eventually leading to decay and deterioration of the deck
- **Prestressing anchorages** – check for corrosion, crushing, and decay
- **Fire damage**

Figure 5.1.8 Wear and Weathering on a Timber Deck

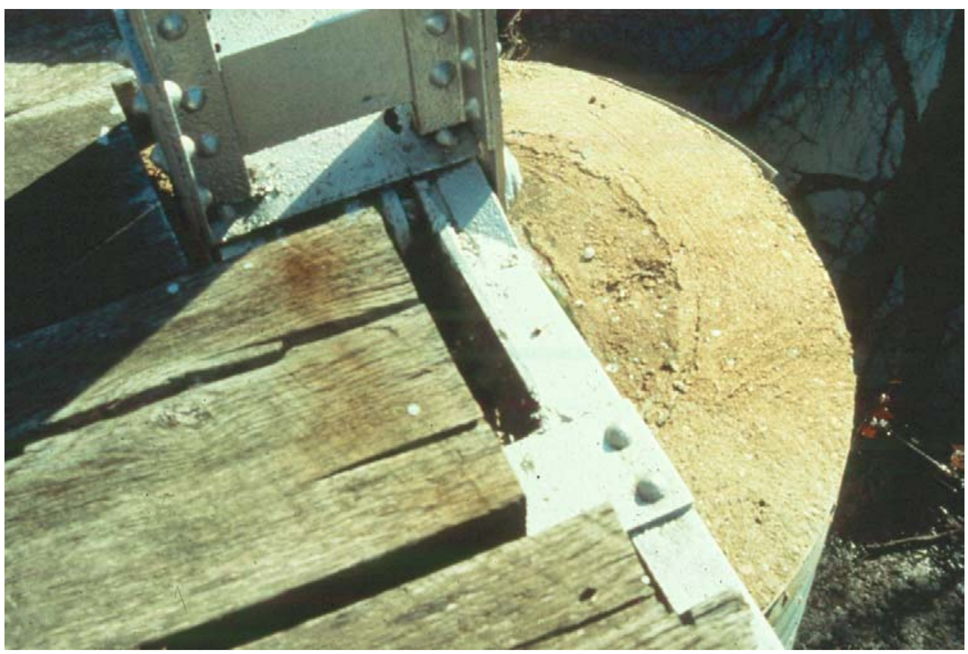

Figure 5.1.9 Bearing Area on a Timber Deck

Figure 5.1.10 Edge of Deck Exposed to Drainage, Resulting in Plant Growth

5.1.7 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of all bridge members, including timber decks. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) component rating method and AASHTO element level condition state assessment method.

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the deck. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 for additional details about the NBIS rating guidelines. The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of deck or slab and the underside. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value.

In an element level condition state assessment of a timber deck, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
031	Timber Deck
032	Timber Deck – with AC Overlay
054	Timber Slab
055	Timber Slab – with AC Overlay

The unit quantity for these elements is "each", and the entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2). Condition state 1 is the best possible rating. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit into a given condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For the purposes of this manual, a deck is supported by a superstructure and a slab is supported by substructure units.

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Topic 5.2 Concrete Decks

5.2.1 Introduction

The most common bridge deck material is concrete. The physical properties of concrete permit casting in various shapes and sizes, providing the bridge designer and the bridge builder with a variety of construction methods. This topic discusses various aspects of concrete bridge decks and related bridge inspection issues.

5.2.2 Design Characteristics

The role of a concrete bridge deck is to provide a smooth riding surface for motorists, divert runoff water, distribute traffic and deck weight loads to the superstructure, and act compositely or non-compositely with the superstructure. Increased research and technology are providing the bridge deck designer with a variety of concrete mix designs, from lightweight concrete to fiber reinforced concrete to high performance concrete, as well as different reinforcement options, to help concrete bridge decks better perform their role.

There are four common types of concrete decks:

- Reinforced cast-in-place (CIP)
- Precast
- Precast prestressed
- Precast prestressed deck panels with CIP topping

Reinforced Cast-in-Place

Concrete decks that are cast in place on the bridge are referred to as "cast-in-place" (CIP). Forms are used to contain reinforcing bars and wet concrete so that after curing, the deck components will be in the correct position and shape. "Bar chairs" are used to support reinforcement in the proper location during casting. There are two types of forms used when placing cast-in-place concrete: removable and stay-in-place.

Removable forms are usually wood planking or plywood but can also be fiberglass reinforced plastic. These forms are removed from the deck after the concrete has cured.

Stay-in-place (SIP) forms are corrugated metal sheets permanently installed above or within the floor system. After the concrete has cured, these forms, as the name indicates, remain in place as permanent, nonworking members of the bridge (see Figure 5.2.1).

Figure 5.2.1 Stay-in-Place Forms

Precast

Precast deck panels are reinforced concrete panels that are cast and cured somewhere other than on the bridge. Precast decks are typically reinforced with conventional mild reinforcement. The slabs are transported to the bridge site, then placed on the bridge, leveled, and attached to the superstructure/floor system. Leveling is generally accomplished using leveling bolts and a grouting system.

The precast deck panels fit together using match cast keyed construction. After leveling, precast deck panels are attached to the superstructure/floor system. Mechanical clips can be used to bolt the deck panels to the stringers. An alternate method involves leaving block-out holes in the precast panels as an opening for shear connectors. The deck panels are positioned over the shear connectors, and the block-out holes are then filled with concrete or grout.

Precast Prestressed

Precast prestressed decks are also reinforced concrete slabs cast and cured away from the bridge site. However, they are reinforced with prestressing steel in addition to some mild reinforcement. The prestressing tendons or bars are tensioned prior to placing the slab (pretensioned) or after the slab is cured (post-tensioned). The tendons are held in position until the slab has sufficiently cured. This creates compressive forces in the slab, which reduce the amount of tension cracking in the cured concrete.

Precast Prestressed Deck Panels with Cast-in-Place Topping

Precast prestressed deck panels can also be used in conjunction with a cast-in-place concrete overlay. Partial depth reinforced precast panels are placed across the beams or stringers and act as forms (see Figure 5.2.2). A cast-in-place layer, which may be reinforced, is then placed which engages both the supporting members and the precast slab units. After the cast-in-place layer has cured, composite action is achieved with the precast deck panels.

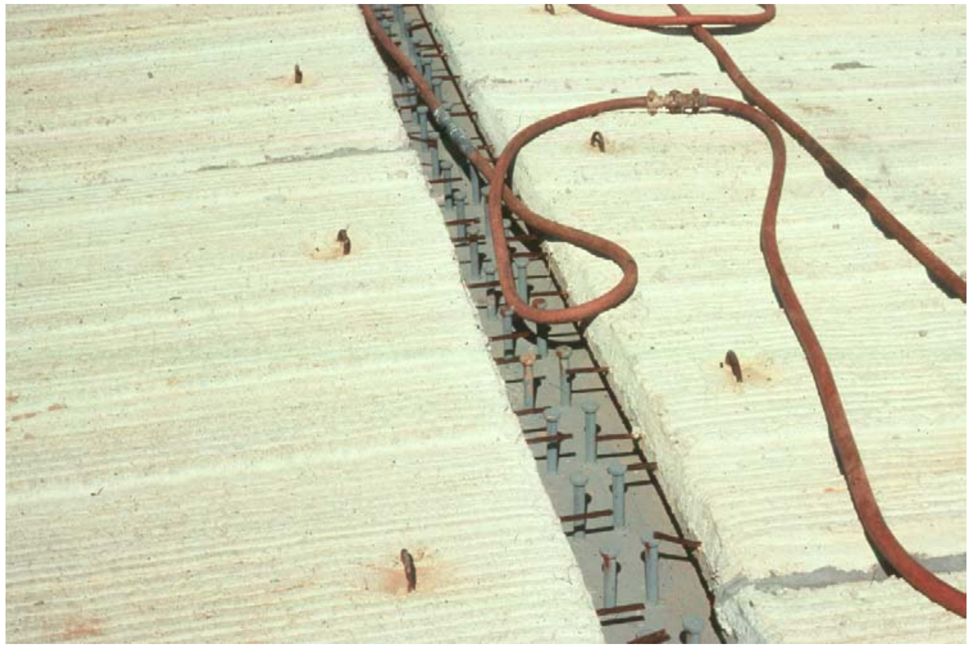

Figure 5.2.2 Precast Deck Panels (with Lifting Lugs Evident and Top Beam Flange Exposed)

In addition to the four common concrete decks, there are two new types of decks that may become more common in the future:

- Fiber reinforced polymer (FRP)
- Fiber reinforced concrete (FRC)

Fiber Reinforced Polymer

New and innovative research is being performed in the area of fiber reinforced polymer (FRP) bridge decks. Most of the FRP composite deck systems use glass reinforcing fibers set in a polyester or vinylester resin matrix. The two most common FRP deck systems use prefabricated panels comprised of pultruded tubes that are glued together with adhesive, and honeycomb or sandwich core systems that are hand-laid up or utilize vacuum assisted resin transfer molding techniques. These deck systems are factory built to the specified deck panel dimension and are then shipped to the erection site. Once at the site, the individual deck panels are bonded together with high performance adhesives. If beams support this type of deck system, a grouted haunch or fillet is required to take into account the imperfections of the beams. Composite action can be developed with FRP deck systems by cutting pockets in the deck to access welded shear studs and then grouting the pockets. Composite action in FRP deck systems is still being researched.

FRP decks require an overlay due to the low skid resistance of the materials. Latex concrete, micro-silica concrete, or dense concrete are not very compatible with FRP deck systems in the areas of stiffness, tensile strength, or compressive strength. Thin epoxy or polymer modified concrete overlays are better suited for use with FRP deck systems. Hot asphalt has been used as an overlay and has worked well over several years on some decks.

An 200 mm (8 inch) deep FRP deck weighs only 98 kg/m^2 (20 pounds per square foot (psf)) compared to 488 kg/m^2 (100 (psf)) for a conventional 200 mm (8 inch) concrete bridge deck.

Fiber Reinforced Concrete

Another new bridge deck material is fiber reinforced concrete (FRC). This type of bridge deck uses common Portland cement concrete mixes with 0.2 to 0.8 percent fiber by volume. The most common type of fiber reinforcement is polypropylene. The purpose of the fiber is to minimize shrinkage cracking of fresh concrete and increase the impact strength of cured concrete.

An FRC bridge deck can either be reinforced with conventional rebar or have no conventional steel reinforcement included in the deck. Initial research testing the ability of polypropylene fibers to block the corrosion of steel reinforcement in concrete bridge decks proved that the fibers did not significantly retard the corrosion process. Therefore, most FRC bridge decks have been designed and constructed without steel reinforcement. FRC decks without steel reinforcement have transverse steel straps welded to the top flange of steel girders and are made composite with the superstructure via shear studs welded to the top flange. The steel straps run the entire width of the deck and provide lateral restraint of the supporting girders. Since no steel reinforcement is included in the deck itself, the deck does not deteriorate due to steel reinforcement corrosion. Therefore, steel-free bridge decks give designers a viable alternative in areas where deicing salts are used.

Composite Action

A concrete deck is generally required when composite action is desired in the superstructure (refer to Topic P.1.10). Composite action is defined as dissimilar materials joined together so they behave as one structural unit. A composite bridge deck structure is one in which the deck acts together structurally with the beams to resist the applied loads. An example of composite action is a cast-in-place concrete deck joined to steel or prestressed concrete beams or a steel floor system using shear connectors (see Figures 5.2.3 and 5.2.4). A precast deck can also develop composite action through grout pockets, which engage shear connectors. Some examples of shear connectors are studs, spirals, channels, or stirrups. Shear connectors are generally welded to steel beams. In concrete beams, shear connectors are simply extended portions of shear stirrups which protrude beyond the top of the casting. Composite action does not occur until the CIP deck is placed and cured or the precast deck grout pockets have been filled and cured.

Non-Composite Member

A non-composite concrete deck is not mechanically attached to the superstructure and does not contribute to the capacity of the superstructure. A non-composite concrete deck only carries wheel loads.

Figure 5.2.3 Shear Connectors Welded to the Top Flange of a Steel Girder

Figure 5.2.4 Prestressed Concrete Beam with Shear Connectors Protruding

Steel Reinforcement

Because concrete has relatively little tensile strength, steel reinforcement is used to resist the tensile stresses in the deck. When reinforcement was first used for bridge decks, it was either round or square steel rods with a smooth finish and had a tendency to “slip” when a tension force was applied. Today, the most common reinforcement is steel deformed reinforcing bars, commonly referred to as "rebars." These bars are basically round in cross section with lugs or deformations rolled into the surface to create a mechanical bond between the bars and the concrete. Lap splices and bar development are dependent on that mechanical bond. A lap splice is the amount of overlap that is needed between two rebars to successfully have the two bars act as one. A typical lap splice length is approximately 30 bar diameters. Mechanical end anchorages or lock devices can also be used to splice rebar. Bar development is the length of embedded rebar needed to develop the design stress and varies based on material properties and bar diameter. For large bars, this length is significant. When space is limited, a mechanical hook (90° or 180° bend) is placed at the end of a bar to achieve full development.

Although concrete decks could not function efficiently without reinforcement, the corrosion of the reinforcing steel is the primary cause of deck deterioration. Since about 1970, epoxy coatings have been a common method of protecting rebars against corrosion. Less common methods of protection include galvanizing and use of stainless steel.

Primary reinforcement carries the tensile stress in a concrete deck and is located on both the top and bottom of the deck. Secondary reinforcement is temperature and shrinkage steel and is placed perpendicular to the primary reinforcement. Additional longitudinal deck reinforcement is generally placed over piers to help resist the negative moments at piers.

The inspector must be able to identify the direction of the primary reinforcement to properly evaluate any cracks in the deck. Primary reinforcement is placed perpendicular to the deck's support points. For example, the support points on a multi-beam bridge and a stringer type floor system are parallel with the direction of traffic. Therefore, the primary deck reinforcement on these deck types is perpendicular to the direction of traffic (see Figure 5.2.5). The support points on a floorbeam-only type floor system are perpendicular with the traffic flow, and the primary deck reinforcement is therefore parallel with the traffic flow. In all cases, the primary reinforcement is closer to the concrete surface.

Figure 5.2.5 Pothole Showing Deck Reinforcing Steel Perpendicular to Traffic

Primary reinforcement is generally a larger bar size than temperature and shrinkage steel. However, to improve design and construction efficiencies, concrete decks may be reinforced with the same size bar in both the top and bottom rebar mats. Reinforcement cover is generally 50 to 64 mm (2 to 2-1/2 inches) minimum for cast-in-place decks without a wearing surface, and 25 mm (1 inch) minimum for precast decks with a separate wearing surface.

5.2.3 Wearing Surfaces

Wearing surfaces are placed on top of the deck. The wearing surface protects the deck and provides a smooth riding surface. The wearing surface materials most commonly used on concrete decks are generally either special concrete mixes or asphalt concrete. Wearing surfaces are incorporated in many new deck designs and are also a common repair procedure for decks.

Concrete

There are two categories of concrete wearing surfaces: integral and overlays. An integral concrete wearing surface is cast with the deck slab, typically adding an extra 13 to 25 mm (1/2 to 1 inch) of thickness to the slab. When the wearing surface has deteriorated to the extent that rideability is affected, it is milled, leveled and replaced with an overlay.

A concrete overlay wearing surface is cast separately over the previously cast concrete deck. Some concrete wearing surfaces may have transverse grooves cut into them as a means of improving traction and preventing hydroplaning. The grooves can be tined while the concrete is still plastic or they can be diamond-sawed after the concrete has cured. There are various types of concrete overlays in use and being researched at the present time. These include:

- Low slump dense concrete (LSDC)
- Polymer/latex modified concrete (LMC)
- Internally sealed concrete
- Lightweight concrete (LWC)
- Fiber reinforced concrete (FRC)

Low slump dense concrete (LSDC) uses a dense concrete with a very low water-cement ratio (approximately 0.32). LSDC overlays were first used in the early 1960's for patches and overlays on bridges in Iowa and Kansas (hence the common term "Iowa Method"). The original overlays were 31 mm (1¼ inches) thick, but now a 50 mm (2-inch) minimum is specified. This type of overlay is generally used because it cures rapidly and has a low permeability. The low permeability resists chloride penetration, while the fast curing decreases the closure period. Low slump dense concrete overlays are placed mainly in locations where deicing salts are used. Surface cracking is a problem in areas where the freeze/thaw cycle exists. The number of applications of deicing salts also plays a role in the deterioration of LSDC overlays. Higher strength dense concrete has been used in the recent past, and results have shown that LSDC overlaid bridge decks will require resurfacing after about 25 years of service, regardless of the concrete deck deterioration caused by steel reinforcement corrosion.

Polymer/latex modified concrete overlay involves the incorporation of polymer emulsions into the fresh concrete. The polymer emulsions have been polymerized prior to being added to the mixture. This is commonly known as latex-modified concrete (LMC). LMC is conventional Portland cement concrete with the addition of approximately 15 percent latex solids by weight of the cement. The typical thickness of 31 mm (1¼ inches) is used for LMC.

The primary difference between the LSDC and the LMC overlays is that low slump concrete uses inexpensive materials but is difficult to place and requires special finishing equipment. Conversely, latex-modified concrete utilizes expensive materials but requires less manpower and is placed by conventional equipment. The performance of LMC has generally been satisfactory, although in some cases, extensive map cracking and debonding have been reported. The causes for this are likely the improper application of the curing method, application under high temperature, or shrinkage due to high slump.

Internally sealed concrete overlays consist of the incorporation of fusible polymeric particles into a concrete mix. After the concrete has cured, the additive is then fused to it. This system, in effect, seals the concrete from moisture and chemicals.

Lightweight concrete (LWC) overlays use concrete with lightweight aggregates and a higher entrained air content. This produces an overlay of approximately 1282 to 1602 kg/m^3 (80 to 100 pcf) compared to 2243 to 2403 kg/m^3 (140 to 150 pcf) for conventional concrete. This type of overlay has a reduced dead load compared to a traditional concrete overlay. Lightweight concrete is also used for cast-in-place and precast decks.

Fiber reinforced concrete (FRC) overlays using Portland cement and metallic, glass, plastic, or natural fibers are becoming a popular solution to bridge deck surface problems. This type of reinforcement strengthens the tension properties in the concrete, and tests have shown that FRC overlays can stop a deck crack from reflecting through the overlay. This type of overlay is gaining acceptance but is still in the research stage.

Asphalt

The most common overlay material for concrete decks is asphalt. Asphalt overlays generally range from 25 mm (1 inch) up to 63 mm (2½ inches), depending on the severity of the repair and the load capacity of the superstructure. When asphalt is placed on concrete, a waterproof membrane may be applied first to protect the reinforced concrete from the adverse effects of water borne deicing chemicals, which pass through the permeable asphalt concrete layer. Not all attempts at providing a waterproof membrane are successful.

5.2.4 Protective Systems

With increasing research, the uses of protective systems are increasing the life of reinforced concrete bridge decks. Most reinforced concrete bridge decks need repair years before the other components of the bridge structure. Therefore protecting the bridge deck from contamination and deterioration is gaining importance.

Sealants

Reinforced concrete deck sealants are used to stop chlorides from contaminating the steel reinforcement. These sealants are generally pore sealers or hydrophobing agents, and their performance is affected by environmental conditions, traffic wear, penetration depth of the sealer, and ultraviolet light.

Boiled linseed oil is a popular sealant that is used to cure or seal a concrete deck.

It is applied after the concrete gains the appropriate amount of strength. This material resists water and the effects of deicing agents.

Elastomeric membranes are another approach when sealing a concrete bridge deck. This type of sealant is mixed on site and cures to a seamless viscous waterproof membrane. It is generally applied prior to placing an asphalt overlay.

Epoxy Coated Reinforcement Bars

Due to the understanding of steel reinforcement corrosion and its effects on the concrete deck, an epoxy coating is often used on all steel reinforcement placed in concrete bridge decks to prevent steel corrosion. The epoxy coating is resistant to chemicals, water, and atmospheric moisture. Epoxies utilize an epoxy polymer binder that forms a tough, resilient film upon drying and curing. Drying is by solvent evaporation, while curing entails a chemical reaction between the coating components.

Galvanized Reinforcement Bars

Another method of protecting steel reinforcement is by galvanizing the steel. This also slows down the corrosion process and lengthens the life of the reinforced concrete slab. Galvanizing is achieved by coating the bare steel reinforcement with zinc. The two unlike metals form an electrical current between them, and one metal virtually stops its corrosion process while the other's accelerates due to the electrical current. In this situation, the steel stops corroding while the zinc has accelerated corrosion.

Stainless Steel Reinforcement Bars

The corrosion process is negligible when stainless steel reinforcement is used.

Fiberglass Reinforced Polymer (FRP) bars

Fiberglass Reinforced Polymer (FRP) bars for concrete reinforcement have the advantage of resistance to corrosion. They are also lightweight, weighing about one-quarter the weight of an equivalent size steel bar.

Cathodic Protection of Reinforcement Bars

Cathodic Protection is sometimes used on decks with black bare steel reinforcement (not epoxy coated). Steel reinforcement corrosion can also be slowed down by cathodic protection. Corrosion of steel reinforcing bars in concrete occurs by an electrical process in a moist environment at the steel surface. During corrosion, a voltage difference (less than 1 volt) develops between rebars or between different areas on the same rebar. Electrons from the iron in the rebar are repelled by the negative anode area of the rebar and attracted to the positive cathode area. This electron flow constitutes an electrical current that is necessary for the corrosion process. Corrosion occurs only at the anode, where the electrons from the iron are given up.

By cathodic protection, this electrical current is reversed, slowing or stopping corrosion. By the impressed current method, an electrical DC rectifier supplies electrical current from local electrical power lines to a separate anode embedded in the concrete. The anode is usually a wire mesh embedded just under the concrete surface. Another type of anode consists of an electrically conductive coating applied to the concrete surface. The wires from the rectifier are embedded in the coating at regular intervals.

When the impressed current enters the mesh or coating anode, the voltage on the rebars is reversed, turning the entire rebar network into a giant cathode. Since natural corrosion occurs only at the anode, the rebars are protected.

The natural corrosion process is allowed to proceed by electrons leaving the iron atoms in the anode. With impressed current cathodic protection, however, the electrons are supplied from an external source, the DC rectifier. Thus, the artificial anode mesh or coating is also spared from corrosion.

Waterproofing Membrane

There are two types of bridge deck waterproofing membrane systems.

- Self-adhering membrane – is a high strength polyester reinforced membrane with a rubber/bitumen compound, which is cold applied. A layer of bituminous base and wearing course is then applied over the membrane.
- Liquid waterproofing membrane – is a two-component compound, which is simply mixed on site to produce a viscous seamless rubber/bitumen liquid that cures to an elastomeric waterproof membrane.

These systems are used to retard reflective cracking and provide waterproofing.

5.2.5 Overview of Common Defects

Common concrete deck defects are listed below. Refer to Topic 2.2 for a detailed description of these defects:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

5.2.6 Inspection Procedures and Locations

Procedures

Visual

The inspection of concrete decks for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

The physical examination of a deck with a hammer can be a tedious operation. In most cases, a chain drag is used. A chain drag is made of several sections of chain attached to pipe that has a handle attached to it. The inspector drags this across a deck and makes note of the resonating sounds. A chain drag can usually cover about a 915 mm (3-feet) wide section of deck at a time (see Figure 5.2.6).

Figure 5.2.6 Inspector Using a Chain Drag

If the inspector deems it necessary, core samples can be taken from the deck and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete bridge decks are caused by corrosion of the rebar. When the deterioration of a concrete deck progresses to the point of needing rehabilitation, an in-depth inspection of the deck is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available.

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection. Nondestructive methods, described in Topic 13.2.2, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electro magnetic methods
- Pulse Velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography

- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.3, include:

- Core Sampling
- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Both the top and bottom surfaces of concrete decks should be inspected for cracking, scaling, spalling, corroding reinforcement, chloride contamination, delamination, and full or partial depth failures. In all instances, it is helpful if the inspector has available the previous inspection report so that the progression of any deterioration can be noted. This provides a more meaningful inspection. Refer to Topic 2.2 for a detailed description of concrete defects.

For concrete deck inspections, special attention should be given to the following locations:

- **Areas exposed to traffic** - examine for surface texture and wheel ruts due to wear. Check cross-slopes for uniformity.

- **Areas exposed to drainage** - investigate for scaling, delamination, and spalls.

- **Bearing and shear areas** where the concrete deck is supported - check for spalls and crushing.

- **Shear key joints** between precast deck panels - inspect for leaking joints, cracks, and other signs of independent action.

- **Anchorage zones** of precast slab tie rods - check for deteriorating grout pockets or loose lock-off devices. If a previous inspection report is available, this should be used by the inspector so that the progression of any deterioration can be noted.

- **Top of the slab** over the supports - examine for flexure cracks.

- **Bottom of the slab** between the supports - check for flexure cracks (see Figure 5.2.7).

- **Asphalt overlays** - if present, they should be inspected. Cracks, delaminations, and spalls are to be noted. Often water penetrates overlays and then penetrates into the structural deck. Asphalt overlays prevent visual inspection of the top surface of the deck.

- **Stay-in-place forms** - investigate for deterioration and corrosion of the forms, often indicating contamination of the concrete deck; these forms can retain moisture and chlorides which have penetrated full depth cracks in the deck (see Figure 5.2.8).

- **Cathodic protection** - during the bridge inspection, check that all visible electrical connections and wiring from the rectifier to the concrete structure are intact. If cathodic protection appears not to be working, notify maintenance personnel. Some agencies that use cathodic protection have specialized inspection/maintenance crews for these types of bridge decks.

Figure 5.2.7 Underside View of Longitudinal Deck Crack

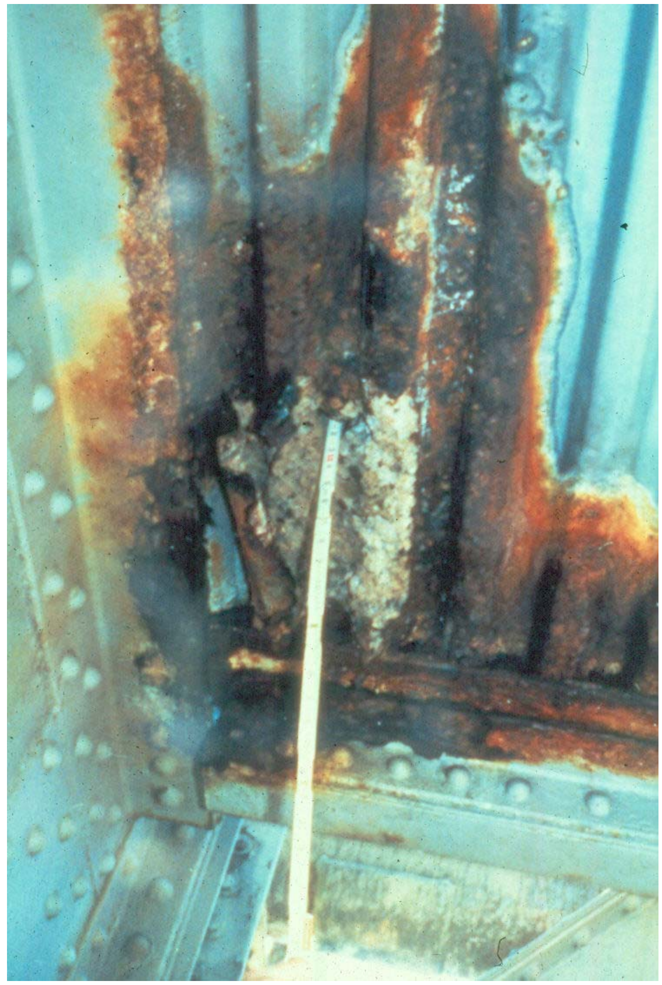

Figure 5.2.8 Deteriorated Stay-in-Place Form

5.2.7 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of concrete decks. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) component rating method and the AASHTO element level condition state assessment method.

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the deck. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 for additional details about the NBIS rating guidelines. The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection - Pontis)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of deck and the underside. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Pontis Smart Flags are also used to describe the condition of the concrete deck.

In an element level condition state assessment of a concrete deck, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	**Description**
012	Concrete Deck – Bare
013	Concrete Deck – Unprotected with AC Overlay
014	Concrete Deck – Protected with AC Overlay
018	Concrete Deck – Protected with Thin Overlay
022	Concrete Deck – Protected with Rigid Overlay
026	Concrete Deck – Protected with Coated Bars
027	Concrete Deck – Protected with Cathodic System

The unit quantity for these elements is "each", and the entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2). Condition state 1 is the best possible rating. The inspector must know the total slab surface area in order to calculate a percent deterioration and fit into a given condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For structural cracks in the surface of bare slabs, the "Deck Cracking" Smart Flag, Element No. 358, can be used and one of four condition states assigned. Do not use Smart Flag, Element No. 358, if the bridge deck/slab has any overlay because the top surface of the structural deck is not visible. For concrete defects on the underside of a slab element, the "Soffit" Smart Flag, Element No. 359, can be used and one of five condition states assigned.

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Section 5

Inspection and Evaluation of Decks

Topic 5.3 Steel Decks

5.3.1 Introduction

Steel decks are found on many older bridges and moveable bridges. Their popularity grew until concrete decks were introduced. Today, steel bridge decks have various advantages and disadvantages, depending on the application, and are mainly used for bridge deck rehabilitation or for very long spans.

5.3.2 Design Characteristics

Steel bridge decks are mainly used when weight is a major factor. The weight of a steel deck per unit area is less than that of concrete. This weight reduction of the deck means the superstructure and substructure can carry more live load. The trade-off for this weight savings is that water is permitted to pass through, which corrodes the superstructure. Steel decks are sometimes filled with concrete to prevent the water from passing through. The four basic types of steel decks are:

- Orthotropic decks
- Buckle plate decks
- Corrugated steel flooring
- Grid decks

Orthotropic Decks

An orthotropic deck consists of a flat, thin steel plate stiffened by a series of closely spaced longitudinal ribs at right angles to the floor beams. The deck acts integrally with the steel superstructure. An orthotropic deck becomes the top flange of the entire floor system. Orthotropic decks are occasionally used on large bridges (see Figure 5.3.1).

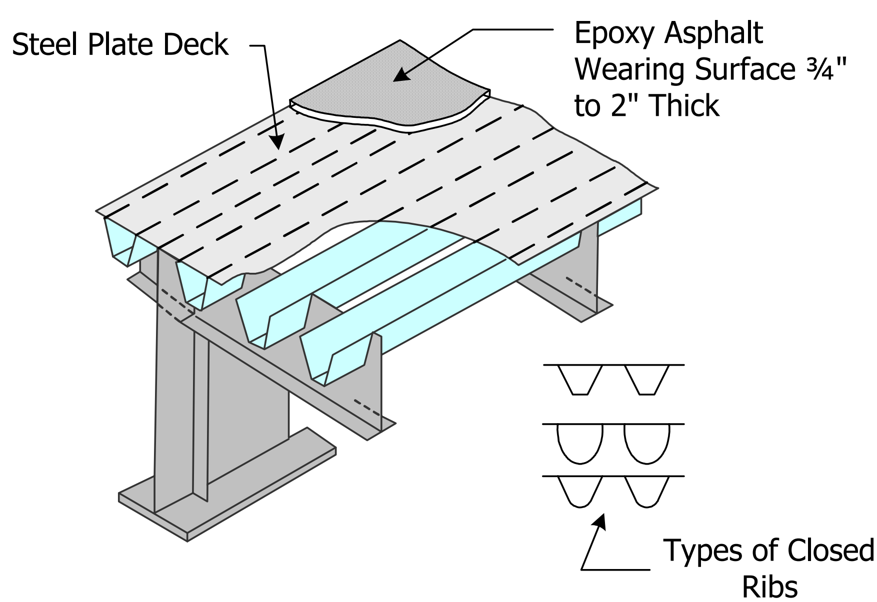

Figure 5.3.1 Orthotropic Bridge Deck

Buckle Plate Decks

Buckle plate decks are found on older bridges. They consist of steel plates attached to the floor system which support a layer of reinforced concrete (see

Figure 5.3.2). The plates are concave or "dished" with drain holes in the center. All four sides are typically riveted to the floor system. Buckle plate decks serve as part of the structural deck and as the deck form. They are obsolete, however, and are no longer used today.

Figure 5.3.2 Underside View of Buckle Plate Deck

Corrugated Steel Flooring

Corrugated steel flooring is popular because of its light weight and high strength. This deck consists of corrugated steel planks covered by a layer of asphalt (see Figure 5.3.3). The planks are set upon the stringers so that the corrugations run perpendicular to the length of the bridge. Corrugations are smaller than stay-in-place (SIP) forms, but the steel is thicker, ranging from 3 mm (0.1 inch) to 5 mm (0.18 inch). The steel planks are welded in place to steel stringers. In the case of timber stringers, the planks are attached by lag bolts. The corrugations are filled with bituminous pavement, and then a wearing surface is applied. This deck is used primarily for the rehabilitation of small bridge decks.

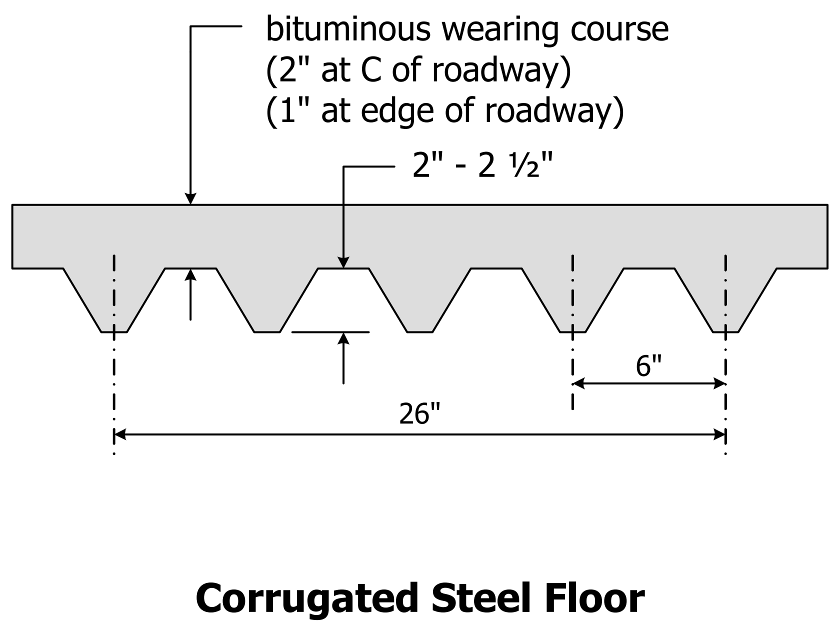

Figure 5.3.3 Sectional View of Corrugated Steel Floor

Grid Decks

Grid decks are probably the most common type of steel deck because of their light weight and high strength. They are commonly welded units, which may be open or filled with concrete.

Open decks are lighter than concrete-filled decks, but they are vulnerable to corrosion since they are continually exposed to weather, debris, and traffic. Another disadvantage of open decks is that they allow dirt and debris to fall onto the supporting members.

Concrete-filled grid decks offer protection for the floor system against water, dirt, debris, and deicing chemicals that usually pass directly through open grid decks. They can be partially-filled or fully-filled.

Partially-filled decks are grid decks which have been partially filled with lightweight concrete. This provides a reduction in the dead load and the protection of a concrete-filled floor system. Grid decks are often found on rehabilitated bridges. Their low weight reduces the dead load on a rehabilitated bridge, and their easy installation reduces the time that the bridge must be closed for repairs.

Fully-filled decks are grid decks that have been completely filled with concrete (see Figure 5.3.4). These decks provide the maximum load carrying capacity. Form pans are welded within the grid to hold the concrete. Filled decks often contain rebars for extra strength.

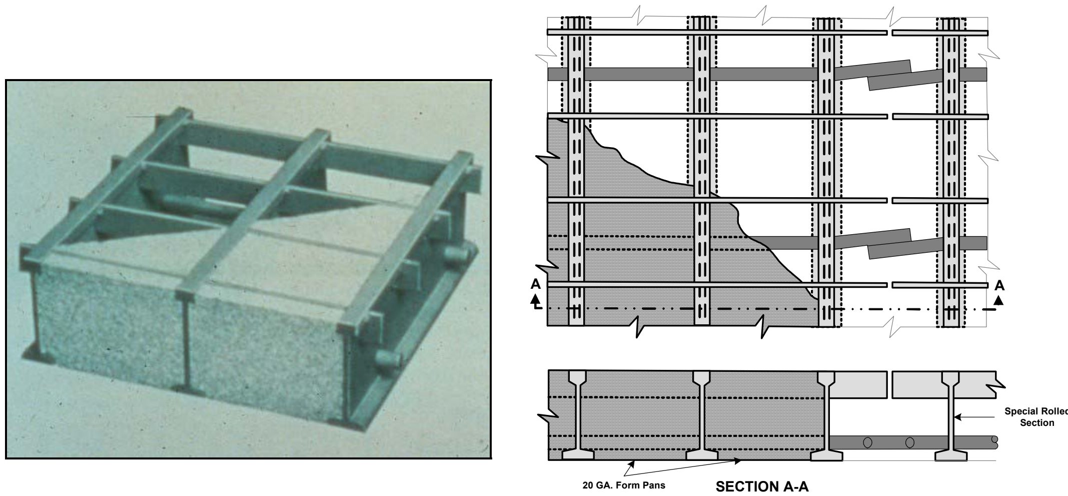

Figure 5.3.4 Schematic of Concrete Filled Grid Deck

The three types of grid decks include:

- Welded grid decks
- Riveted grate decks
- Exodermic decks

Welded Grid Decks

Welded grid decks have their components welded together. These components consist of bearing bars, cross bars, and supplementary bars (see Figure 5.3.5).

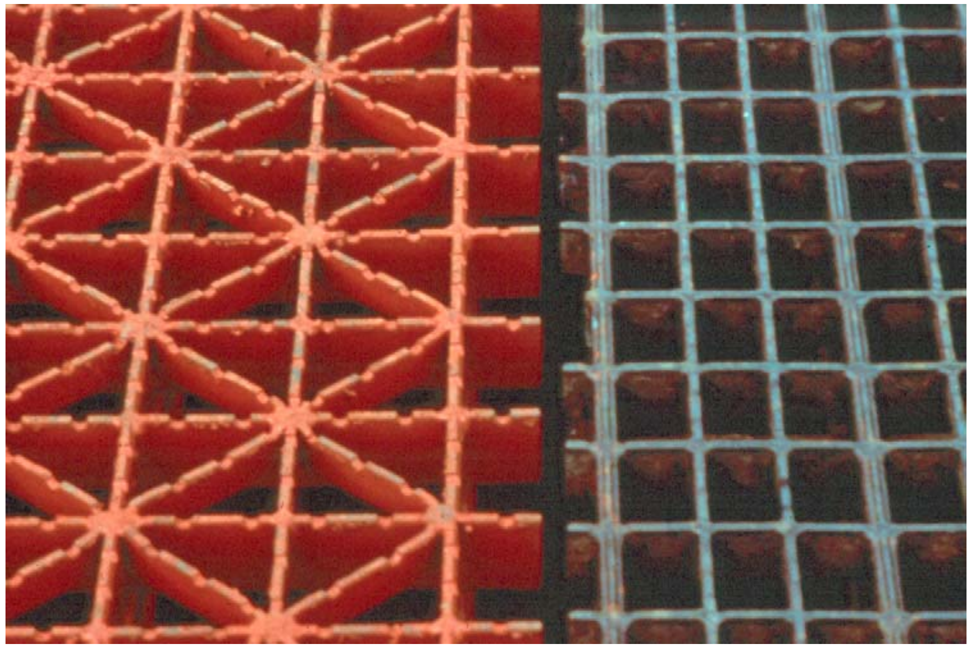

Figure 5.3.5 Various Patterns of Welded Steel Grid Decks

The bearing bars support the grating. Bearing bars are laid on top of the stringers perpendicularly and are then field-welded or bolted to the stringers. These bars are also referred to as the primary or main bars.

The cross bars are grating bars that are laid perpendicular on top of the bearing bars. They may be either shop- or field-welded to the grating system. Cross bars, also referred to as secondary bars or distribution bars, are generally serrated for improved traction.

The supplementary bars are grating bars that run parallel to the bearing bars. They are also shop- or field-welded to the grating system. Not all grating systems have supplementary bars. These bars are also referred to as tertiary bars.

Riveted Grid Decks

A riveted grid deck is made up of bearing bars, crimp bars, and intermediate bars and can either be fully or partially filled with concrete to improve the load carrying capacity of the deck (see Figure 5.3.6).

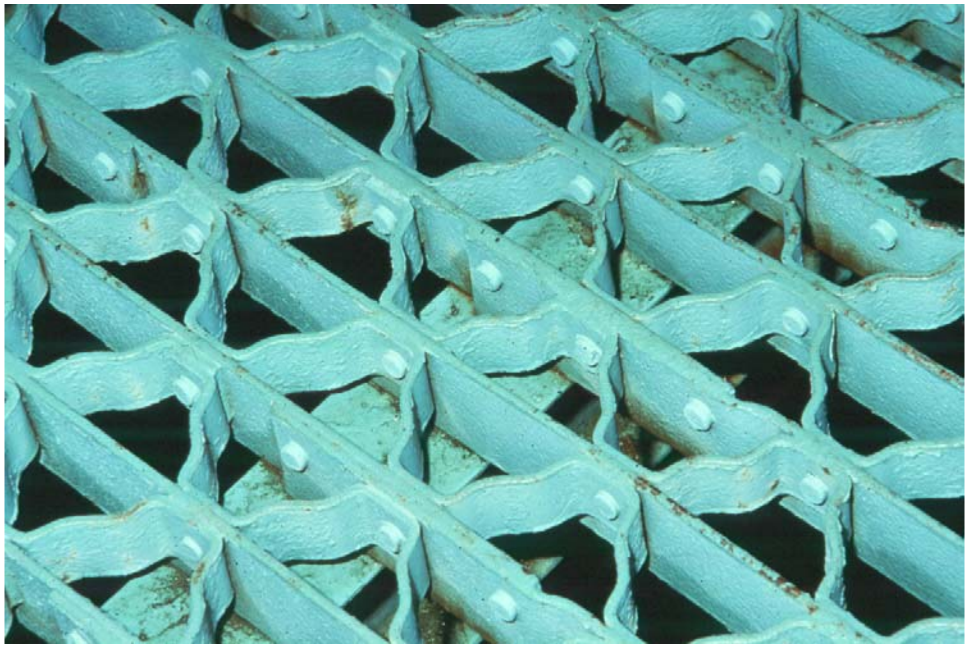

Figure 5.3.6 Riveted Grid Deck

Bearing bars run perpendicular to the stringers and are attached to the stringers by either welds or bolts. They are similar to the bearing bars in welded grates.

Crimp bars are riveted to the bearing bars to form the grating.

Intermediate bars run parallel to the bearing bars but, in order to reduce the weight of the deck, are not as long. The crimp bars are riveted to intermediate bars and may not be present on all riveted grate decks.

Exodermic Decks

Exodermic decks are a newer type of bridge deck in which a reinforced concrete slab is placed on top of, and is made composite with, a steel grid (see Figure 5.3.7). Composite action is achieved by studs that extend into the reinforced concrete slab and are welded to the grid deck below. Galvanized sheeting is used as a bottom form to keep the concrete from falling through the grid holes. Exodermic decks generally weigh 50% to 65% lighter than precast reinforced concrete decks.

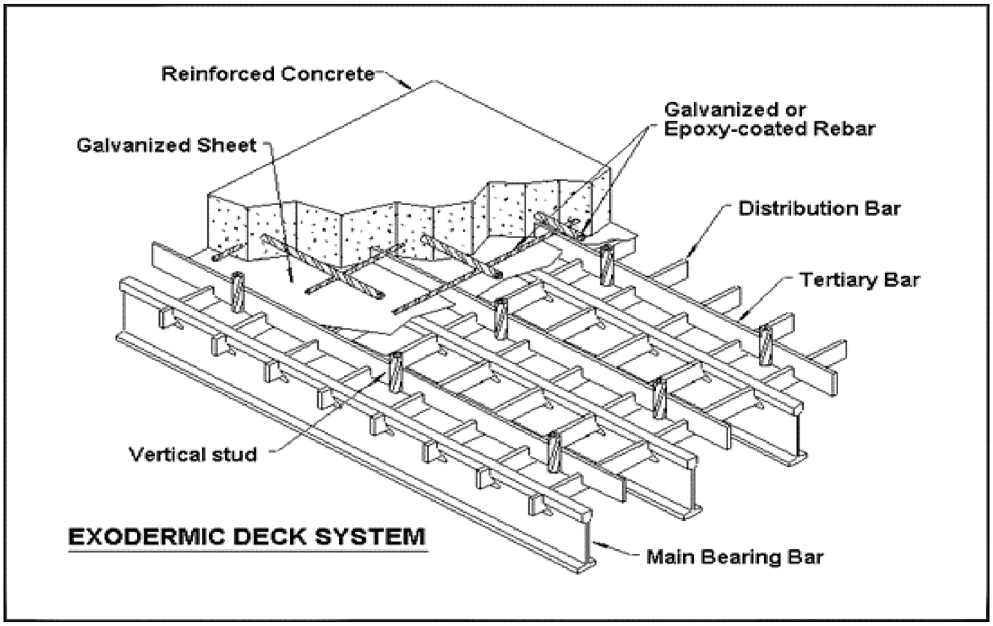

Figure 5.3.7 Schematic of Exodermic Composite Profile

5.3.3 Wearing Surfaces

Wearing surfaces protect the steel deck, provide an even riding surface, and reduce the water on the deck and superstructure. Wearing surfaces for steel decks can consist of:

- Serrated steel
- Concrete
- Asphalt

Studs can be welded to steel decks for skid resistance.

Serrated Steel

Open grid decks usually have serrated edges on the grating (see Figure 5.3.5). Designed not to wear, these serrations make up the riding surface of an open grid deck.

Concrete

Acting as the wearing surface, fully and partially filled grid decks have a layer of concrete flush with the top of the grids. This concrete wearing surface and the concrete used to fill the grids are generally poured at the same time. Different types of concrete wearing surfaces are listed and described in Topic 5.2.3. In the case of an exodermic bridge deck, the wearing surface is part of a reinforced deck made composite with an unfilled steel grid system and attached by means of vertical studs.

Asphalt

Steel plate decks, such as orthotropic decks, typically have a layer of asphalt as the wearing surface. Asphalt overlays generally range from 25 mm (1 inch) up to 63 mm (2½ inches), depending on the severity of the repair and the load capacity of the superstructure. Corrugated steel plank decks also have asphalt wearing surfaces.

An epoxy asphalt polymer concrete also is used for orthotropic bridge deck wearing surfaces. Unlike conventional asphalt mixes, epoxy asphalt polymer concrete will not melt after it has cured due to having a thermoset polymer in the mix. This polymer is different than thermoplastic polymer, which is used in conventional asphalt mixes. Therefore epoxy asphalt polymer concrete is used when strength and elastic composition are important.

5.3.4 Protective Systems

Paints

Paints provide protection from moisture, oxygen, and chlorides. Usually three coats of paint are applied. The first coat is the primer, the next is the intermediate coat, and the final coat is the topcoat. Various types of paint are used, such as oil/alkyd, vinyl, epoxy, urethane, zinc-rich primer, and latex paints.

Galvanizing

Another method of protecting steel decks is by galvanizing the steel. This also slows down the corrosion process and lengthens the life of the steel deck. This occurs by coating the bare steel with zinc. The two unlike metals form an electrical current between them and one metal virtually stops its corrosion process while the other's accelerates due to the electrical current. In this situation, the steel stops corroding, while the zinc has accelerated corrosion.

There are two methods of galvanizing steel decks (shop applied and field applied). Hot-dipping the steel deck members usually takes place at a fabrication shop prior to the initial placement of the steel deck. When sections of the deck are too large or when maintenance painting is to take place, the zinc-rich-primers can be applied in the field. The zinc paint must be mixed properly, and the surface must be prepared correctly.

Overlay

Another protective system for steel decks is the overlay material itself. The overlay covers the steel to create a barrier from corrosive agents. Overlays slow down the deterioration process for steel decks.

Epoxy Coating

Epoxy coating steel grates is another means of protecting the steel decking. This is a rare type of protective coating for steel bridge decks, but there are a limited number still in service.

5.3.5 Overview of Common Defects

Some of the common steel deck defects are listed below. Refer to Topic 2.3 to review steel defects in detail.

- Bent, damaged, or missing members
- Corrosion
- Fatigue cracks
- Other stress-related cracks

5.3.6 Inspection Procedures and Locations

Steel decks should be visually inspected for broken welds, failed fasteners, broken grids, and section loss (see Figure 5.3.8).

Procedures

Visual

The inspection of steel decks for corrosion, section loss, buckling, and cracking is primarily a visual activity. Reference Topic 2.3 for a more detailed explanation of visual inspection procedures.

Physical

Once the defects are identified visually, physical procedures must be used to verify the extent of the defect. For steel members, the main physical inspection procedures involve an inspection hammer and wire brush. Corrosion results in loss of member material. This partial loss of cross section due to corrosion is known as section loss. Section loss may be measured using a straight edge and a tape measure. However, a more exact method of measurement, such as calipers or a D-meter, should be used to measure the remaining section of steel. The inspector must remove all corrosion products (rust scale) prior to making measurements.

The inspector should measure the bridge members to verify that the sizes recorded in the plans or inspection report are accurate. If incorrect member sizes are used, then any load rating analysis for safe load capacity of the bridge is worthless.

Advanced Inspection Techniques

In addition, several advanced techniques are available for steel inspection. Nondestructive methods, described in Topic 13.3.2, include:

- Acoustic emissions testing
- Computer Programs
- Computer tomography
- Corrosion sensors
- Dye penetrant
- Magnetic particle
- Radiographic testing
- Robotic inspection
- Ultrasonic testing
- Eddy current

Other methods, described in Topic 13.3.3, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

Locations

The primary locations for steel deck inspection include:

- **Bearing areas** - check for cracked welds or broken fasteners, which connect the steel deck to the supporting floor system.

- **Primary bearing bars** - inspect for broken, cracked, or missing bars.

- **Tension areas** - on steel grid decks, check positive and negative moment regions of the primary bearing bars. Look for damage such as broken, cracked, or missing bars.

- **Areas exposed to drainage** - check areas where drainage can lead to corrosion.

- **Corrugated flooring** - check between the support points for section loss due to corrosion.

- **Check for slipperiness** on steel grid decks caused by excessive wear.

- **Section loss** - in areas where corrosion is evident, all scale should be removed with an inspection hammer in order to evaluate the amount of remaining material.

- **Connections** - examine for broken connections, and listen for rattles as traffic passes over the deck.

- **Filled grid decks** - inspect for grid expansion at joints and bridge ends, often caused by corrosion.

- **Corrosion** - on corrugated flooring, check between the support points for section loss due to corrosion. In areas where corrosion is evident, all scale should be removed with an inspection hammer in order to evaluate the amount of remaining material. Document the location and condition of any repair plates.

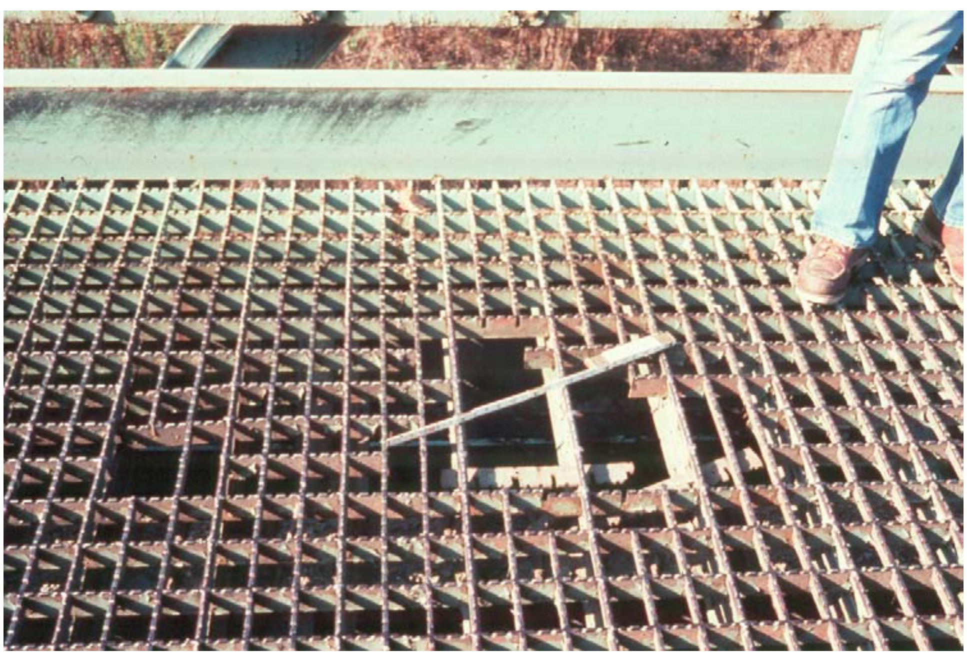

Figure 5.3.8 Broken Members of an Open Steel Grid Deck

5.3.7 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of steel decks. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) component rating method and the AASHTO element level condition state assessment method.

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the deck. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 for additional details about the NBIS rating guidelines. The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection - Pontis)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the top of deck and the underside. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value.

In an element level condition state assessment of a steel deck, the AASHTO CoRe element is one of the following, depending on the riding surface:

Element No.	Description
028	Steel Deck – Open Grid
029	Steel Deck – Concrete Filled Grid
030	Steel Deck – Corrugated/ Orthotropic

The unit quantity for these elements is "each", and the entire element must be placed in one of the five available condition states based solely on the surface condition. Some states have elected to use the total area (m^2 or ft^2). Condition state 1 is the best possible rating. The inspector must know the total deck surface area in order to calculate a percent deterioration and fit into a given condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For connections of steel decks showing rust packing between steel plates, the "Pack Rust" Smart Flag, Element No. 357, can be used and one of four condition states assigned.

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Section 5

Inspection and Evaluation of Decks

Topic 5.4 Deck Joints, Drainage Systems, Lighting and Signs

5.4.1 Function of Deck Joints, Drainage Systems, Lighting and Signs

Deck Joints

The deck joint is a very important part of a bridge. The primary function of deck joints is to accommodate the expansion and contraction of the deck and superstructure. In most bridges, the deck joints must accommodate this movement and prevent runoff from reaching bridge elements below the surface of the deck. In addition, the deck joint provides a smooth transition from the approach roadway to the bridge deck. The deck joint must be able to withstand all possible weather extremes in a given area. It must do all of this without compromising the ride quality of vehicles crossing the bridge.

Drainage Systems

The purpose of a drainage system is to remove water and all hazards associated with it from the structure. The drainage system should also require as little maintenance as possible and be located so that it does not cause hazards.

Lighting and Signs

Lighting serves various functions on bridge structures, depending on location and color. Highway lighting is used to increase visibility on a bridge structure. Traffic signal lighting controls traffic on a structure. Aerial obstruction lighting warns aircrafts of a hazard around and below the lights. Navigational lighting is used for the safe control of waterway traffic under a bridge structure. Finally, sign lighting ensures proper visibility for traffic signs.

Typical signs that are present on or near bridges provide regulatory (e.g., speed limits) information and advisory (e.g., clearance warnings) information. Such signs serve to inform the motorist about bridge or roadway conditions that may be hazardous.

5.4.2 Components of Deck Joints, Drainage Systems, Lighting and Signs

Deck Joints

Deck joints should not be confused with construction joints. While deck joints are used primarily to facilitate expansion and contraction of the deck and superstructure, construction joints mark the beginning or end of concrete placement sections during the construction of the bridge deck. The two major categories of deck joints are open joints and closed joints.

Open Joints

Open joints allow water and debris to pass through the joint. The two types of open joints are as follows:

- Formed joints
- Finger plate joints

Formed Joints

Formed joints are little more than a gap between the bridge deck and the abutment backwall or, in the case of a multiple span structure, between adjacent deck sections. They are usually found on very short span bridges where expansion is minimal. The formed joint is usually unprotected, but the deck slab and backwall can be armored with steel angles. Formed joints are common on short span bridges with concrete decks (see Figures 5.4.1 and 5.4.2).

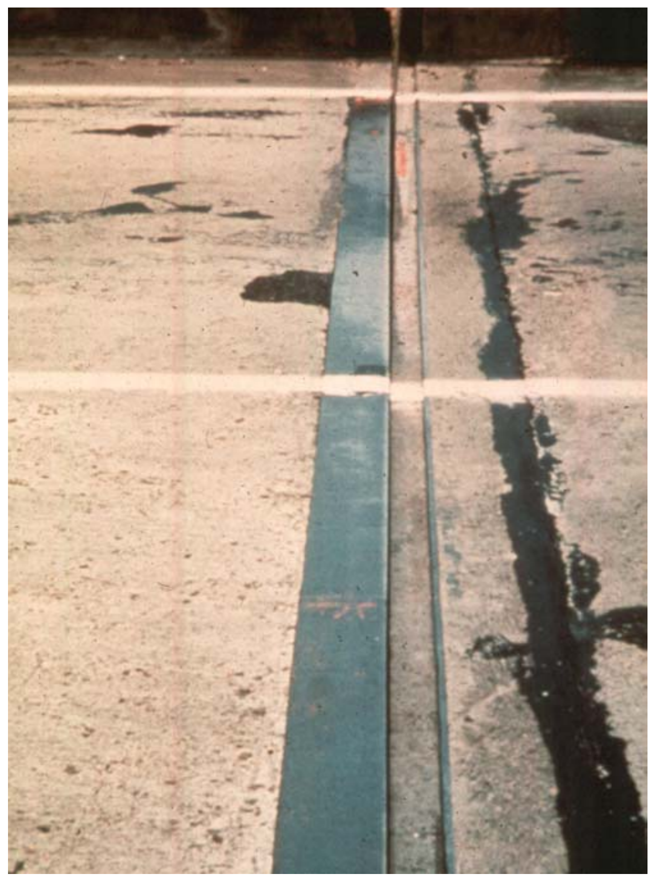

Figure 5.4.1 Formed Joint

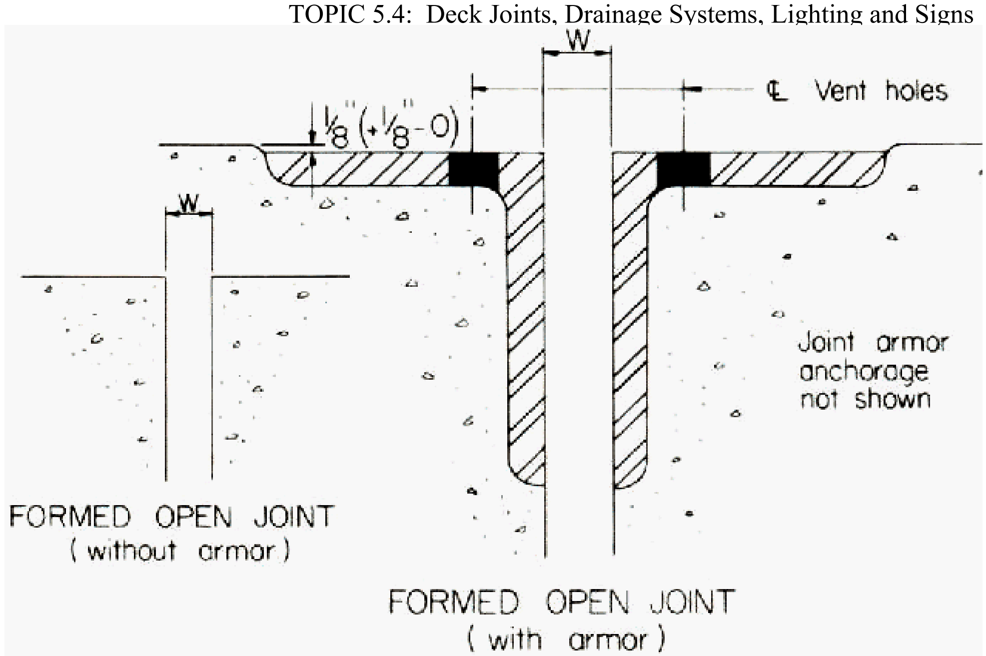

Figure 5.4.2 Cross Section of a Formed Joint

Finger Plate Joints

A finger plate joint, also known as a tooth plate joint or a tooth dam, consists of two steel plates with interlocking fingers. These joints are usually found on longer span bridges where greater expansion is required. The two types of finger plate joints are cantilever finger plate joints and supported finger plate joints.

The cantilever finger plate joint is used when relatively little expansion is required. The fingers on this joint cantilever out from the deck side plate and the abutment side plate. The supported finger plate joint is used on longer spans. The fingers on this joint have their own support system in the form of transverse beams under the joint. Some types of finger plate joints are segmental, allowing for maintenance and replacement if necessary. Finger plate joints are used to accommodate movement from 100 to over 600 mm (4 to over 24 inches) (see Figures 5.4.3 through 5.4.5).

Troughs are sometimes placed under open finger plate joints. Their purpose is to direct water that passes through the joint away from the superstructure, bearings and substructure.

Figure 5.4.3 Finger Plate Joint

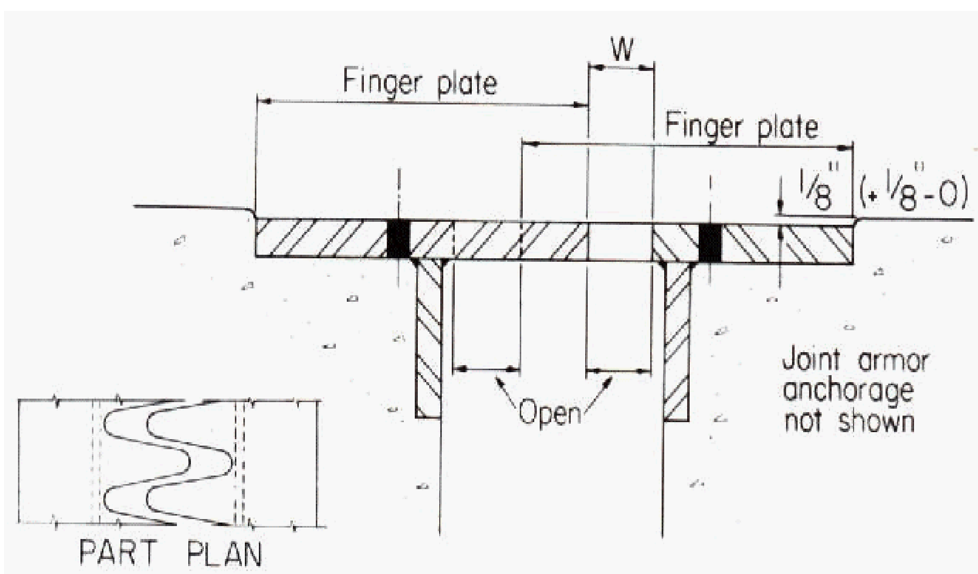

Figure 5.4.4 Cross Section of a Cantilever Finger Plate Joint

Figure 5.4.5 Supported Finger Plate Joint

Closed Joints

Closed joints are designed so that water and debris do not pass through them. This protects the superstructure and substructure members directly below the joint from the effects of water and debris buildup. There are many types of closed joints, including the following:

- Poured joint seal
- Compression seal
- Cellular seal
- Sliding plate joint
- Prefabricated elastomeric seal
- Modular elastomeric seal
- Asphaltic expansion joint

Poured Joint Seal

A poured joint seal is made up of two materials: a base and a poured sealant. The base consists of a preformed expansion joint filler. The top of this material is 25 to 50 mm (1 to 2 inches) from the top of the deck. The remaining joint space consists of the poured sealant that is separated from the base by a backer rod or a bond breaker. Since the poured joint seal can only accommodate a movement of about 6 mm (1/4 inch), it is usually found on short span structures.

Compression Seal

A compression seal consists of neoprene formed in a rectangular shape with a honeycomb cross section (see Figure 5.4.6). The honeycomb design allows the compression seal to fully recover after being distorted during bridge expansion and contraction. It is called a compression seal because it functions in a partially compressed state at all times. Compression seals can have steel angle armoring on the deck and backwall. In some cases, the deck joint is saw cut to accept the installation of the compression seal. In such cases, no armoring is provided. These seals come in a variety of sizes and are often classified by their maximum movement capacity. A large compression seal can accommodate a maximum movement of approximately 50 mm (2 inches).

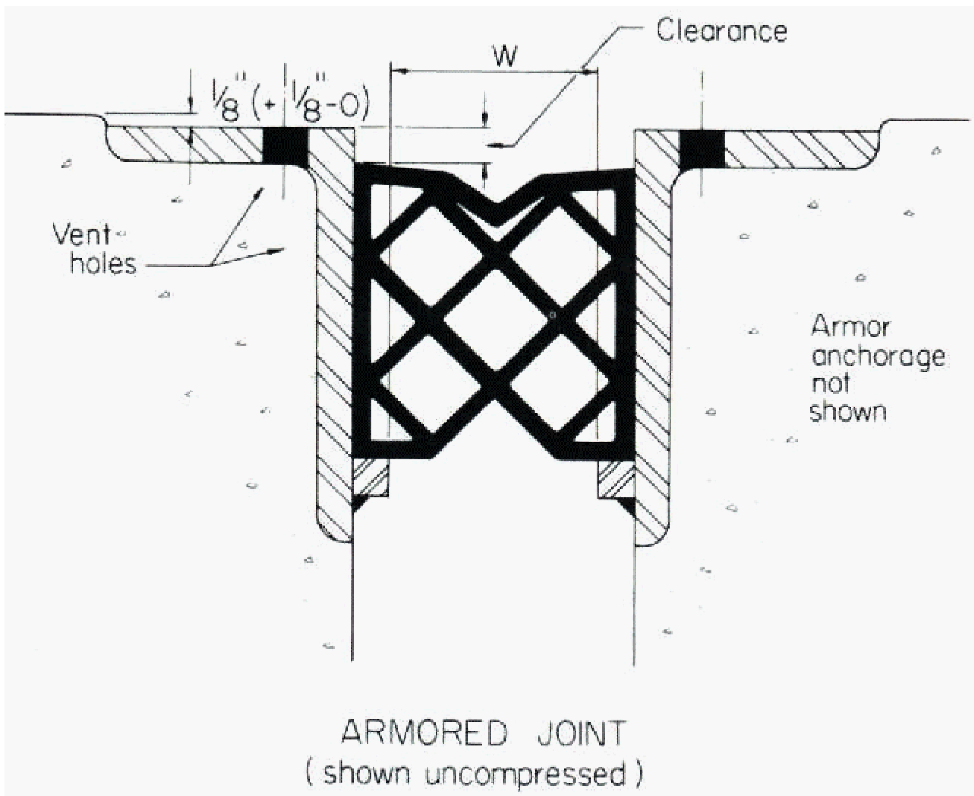

Figure 5.4.6 Cross Section of a Compression Seal with Steel Angle Armoring

Cellular Seal

The cellular seal is similar to the compression seal, and its armoring is almost identical. However, they differ in the type of material used to seal the joint. Unlike the compression seal, the cellular seal is made of a closed-cell foam that allows the joint to move in different directions without losing the seal. This foam allows for expansion and contraction both parallel and perpendicular to the joint. The parallel movement is referred to as racking and occurs during normal expansion and contraction of a curved structure or a bridge on a skew.

Sliding Plate Joint

A sliding plate joint is composed of two plates sliding on top of each other.

Although classified as a closed joint, the sliding plate joint is usually not watertight. In an attempt to seal the joint, an elastomeric sheet is sometimes used. This sheet is attached between the plates and the joint armoring. The resulting trough serves to carry water away to the sides of the deck (see Figure 5.4.7). The sliding plate joint can accommodate a maximum movement of approximately 100 mm (4 inches).

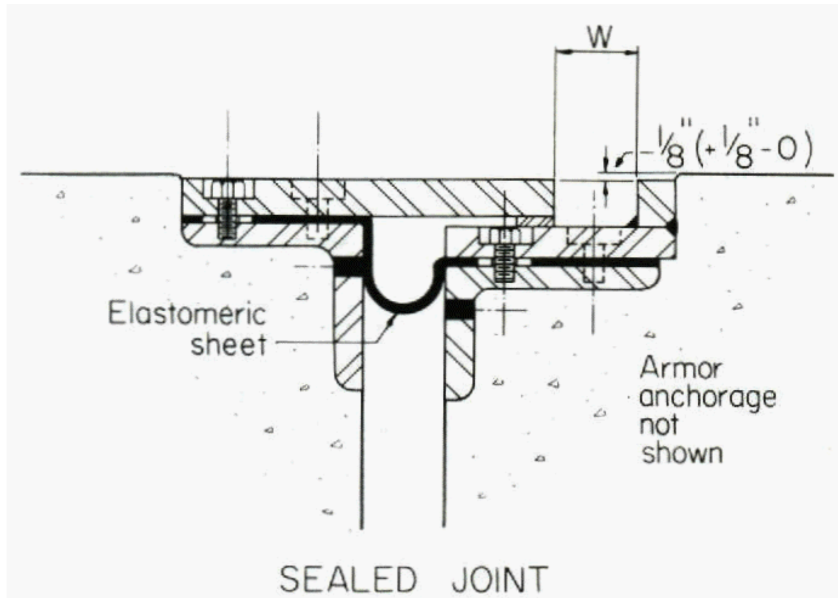

Figure 5.4.7 Cross Section of a Sliding Plate Joint

Prefabricated Elastomeric Seal

Prefabricated elastomeric seals are frequently proprietary products and include three basic types:

- Plank seal
- Sheet seal
- Strip seal

A plank seal consists of steel reinforced neoprene that supports vehicular wheel loads over the joint. This type of seal is bolted to the deck and is capable of accommodating movement ranges from 50 to 330 mm (2 to 13 inches) (see Figure 5.4.8).

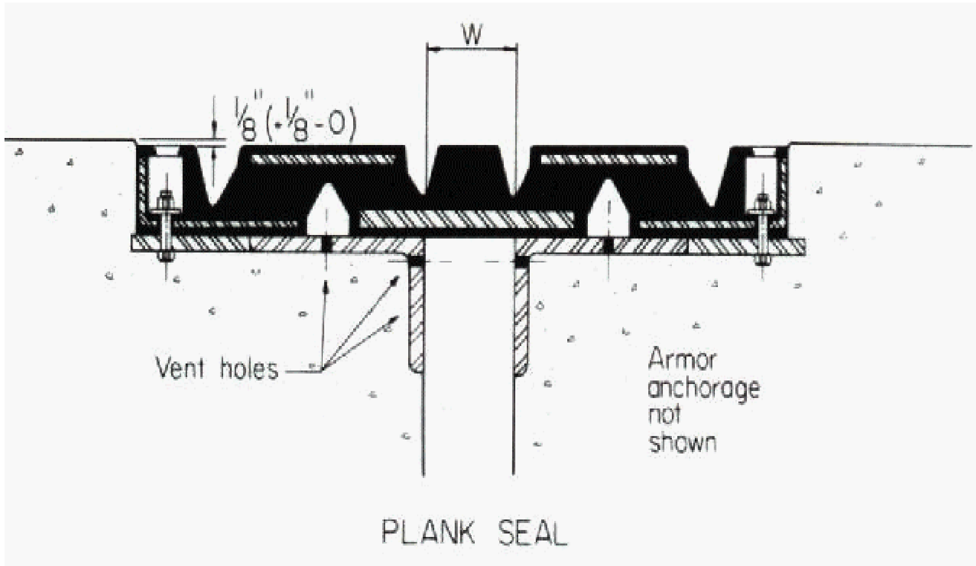

Figure 5.4.8 Plank Seal

A sheet seal consists of two blocks of steel reinforced neoprene. A thin sheet of neoprene spans the joint and connects the two blocks. This joint can accommodate a maximum movement of approximately 100 mm (4 inches) (see Figure 5.4.9).

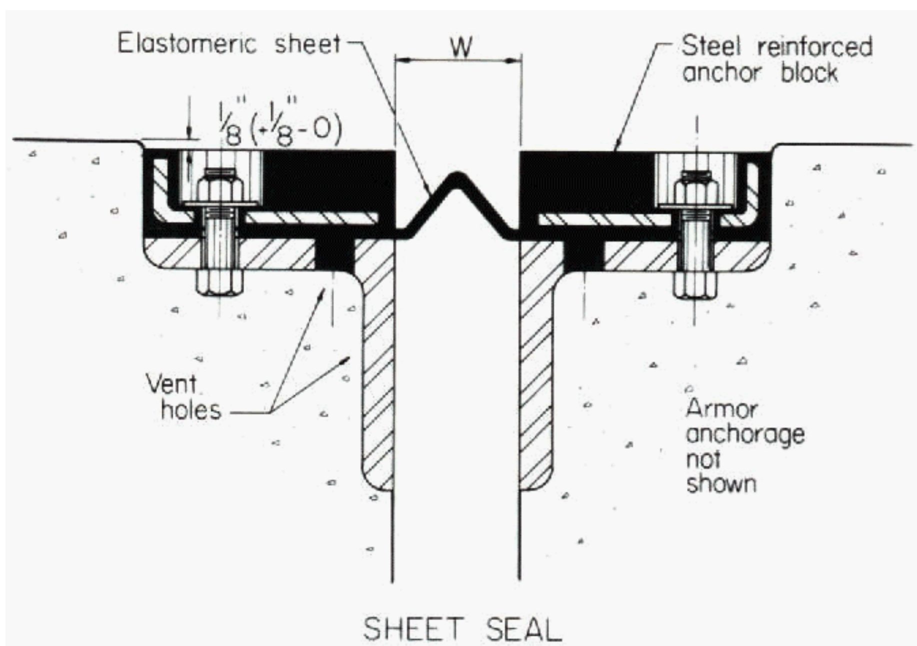

Figure 5.4.9 Sheet Seal

A strip seal consists of two slotted steel anchorages cast into the deck and backwall. A neoprene seal fits into the grooves to span the joint. This joint can accommodate a maximum movement of approximately 100 mm (4 inches) (see Figure 5.4.10).

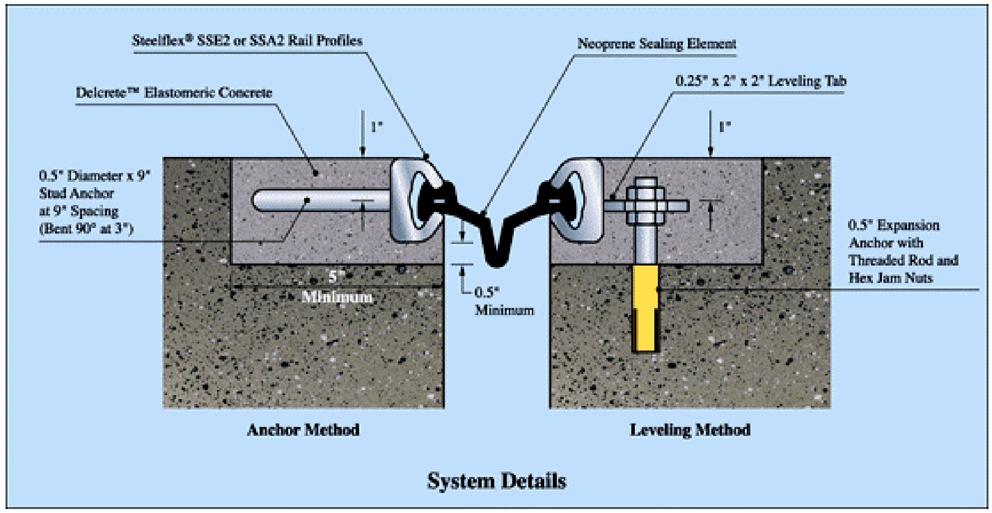

Figure 5.4.10 Strip Seal (Drawing Courtesy of the D.S. Brown Co.)

Modular Elastomeric Seal

The modular elastomeric seal is another neoprene type seal which can support vehicular wheel loads. It consists of hollow, rectangular neoprene block seals, interconnected with steel and supported by its own stringer system (see Figure 5.4.11). The normal range of operation for movement is between 100 and 600 mm (4 and 24 inches). It can, however, be fabricated to accommodate movements up to 1200 mm (48 inches).

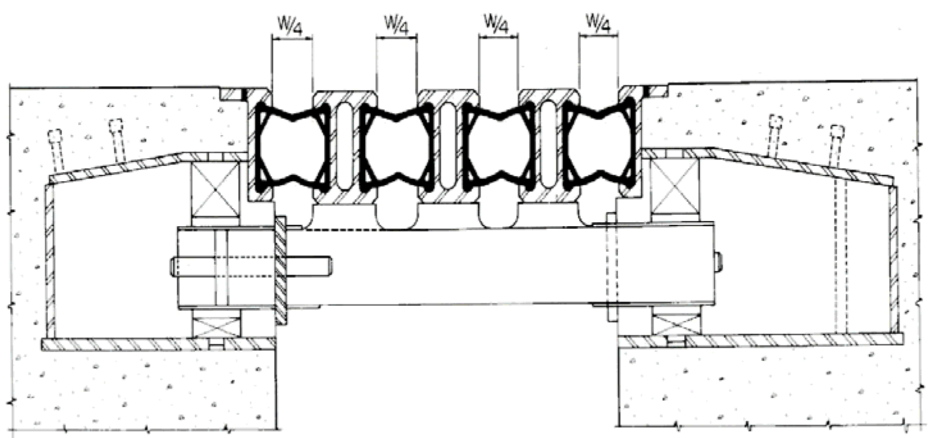

Figure 5.4.11 Schematic Cross Section of a Modular Elastomeric Seal

Asphaltic Expansion Joint

An asphaltic expansion joint is typically used on short bridges that are to be overlaid with asphalt. The joint expansion must be 50 mm (2 inches) or less. The original joint is usually a formed open joint that has deteriorated. Once the bridge joint is overlaid, the overlay material on the joint and a set distance in both directions of the joint is removed down to the original deck. A backer rod is then placed in the open joint and a sealant material is placed in the joint. Next, an aluminum or steel plate is centered over the joint to bridge the opening, and pins are put through the plate into the joint to hold it in place. A heated binder material is then poured on the plate to create a watertight seal. Layers of aggregate saturated with hot binder are then placed to the depth needed. The filled joint is then compacted. This type of joint allows for bridge decks to be overlaid without damaging existing expansion joints and is gaining popularity (see Figure 5.4.12).

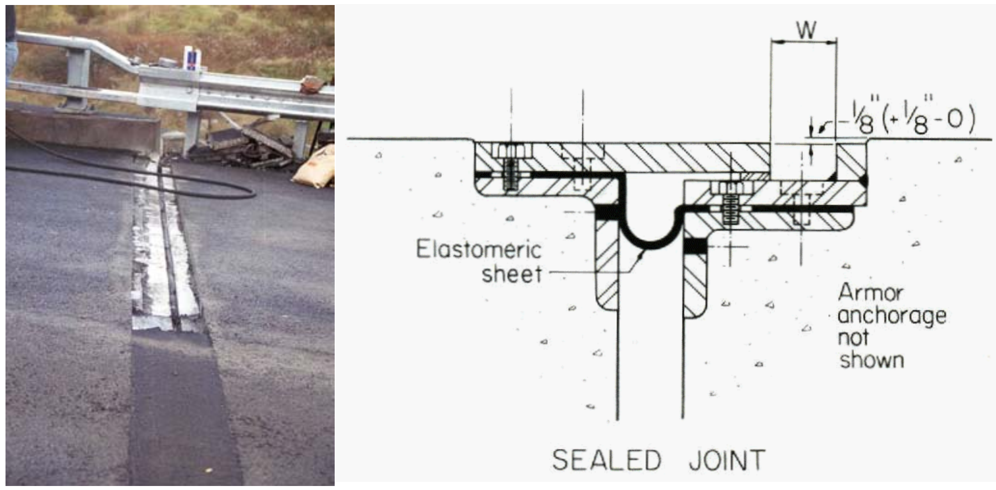

Figure 5.4.12 Asphaltic Expansion Joint

Drainage Systems

In order to perform an inspection of a deck drainage system, it is necessary to become familiar with its various elements:

- Runoff
- Bridge deck cross slope and profile
- Deck drains
- Outlet pipes
- Downspout pipes
- Cleanout plugs

Runoff

Runoff is the water and any contents that may run off the surface of the bridge deck.

Bridge Deck Cross Slope and Profile

The cross slope of the bridge deck is the first component of the drainage system that the runoff encounters. The proper cross slope and profile directs the runoff to the deck drains and eliminates or reduces ponding.

Deck Drains

The deck drain is the second component of the drainage system that runoff encounters. A deck drain is a receptacle to receive water. Deck drains may be nothing more than openings in a filled grid deck, holes in a concrete deck, or slots in the base of a parapet. Inlet boxes and scuppers are also examples of deck drains (see Figure 5.4.13).

Figure 5.4.13 Bridge Deck Inlet

Inlet boxes have a grate, which is a ribbed or perforated cover. Grates are fabricated from steel bars that are frequently oriented with the longitudinal direction of the bridge and spaced at approximately 50 mm (2 inches) on center. A bicycle safety grate has steel rods placed perpendicular to the grating bars, spaced at approximately 100 mm (4 inches) on center.

Grates keep larger debris from entering the drainage system while allowing water to pass through. They also serve to support traffic and other live loads. The drainage system may end with the deck drain.

Outlet Pipes

The outlet pipe leads water away from the drain. For bridges over roadways, the outlet pipe connects to other pipes. When the bridge is not over a roadway, the outlet pipe may simply extend a few feet down from the deck so that drainage water is not windblown onto the superstructure.

Downspout Pipes

When a bridge is located over a roadway, the deck drainage must be directed from the outlet pipe to a nearby storm sewer system or another appropriate release point. This is accomplished with a downspout pipe network (see Figure 5.4.14).

Cleanout Plugs

The cleanout plug is a removable plug in the piping system that allows access for cleaning.

Figure 5.4.14 Downspout Pipe and Cleanout Plug

Lighting

The four basic types of lighting which may be encountered on a bridge are:

- Highway lighting
- Traffic control lighting
- Aerial obstruction lighting
- Navigation lighting

Highway Lighting

The typical highway lighting standard consists of a lamp or luminaire attached to a bracket arm. Both the luminaire and bracket arm are usually made of aluminum. The bracket arm is attached to a shaft or pole made of concrete, steel, cast iron, aluminum, or, in some cases, timber. It is generally tapered toward the top of the pole.

The shaft is attached at the bottom to an anchor base. Steel and aluminum shafts are fitted inside and welded to the base. In the case of concrete, the shaft is normally cast as an integral part of the base. Sometimes the thickness of the parapet or median barrier is increased to accommodate the anchor base. This area of the barrier or parapet is called a “blister”. Where the standard is exposed to vehicular traffic, a breakaway type base or guardrail may be used. Anchor bolts hold the light standard in place. These L-shaped or U-shaped bolts are normally embedded in a concrete foundation, parapet, or median barrier.

Traffic Control Lighting

Traffic control lights are used to direct traffic flow on a structure. Lights can serve a similar purpose to those found at intersections, but they can also indicate which lanes vehicular traffic is to use. These are referred to as lane control signals. Red and green overhead lights indicate the appropriate travel lanes.

Aerial Obstruction Lighting

Aerial obstruction lights are used to alert aircraft pilots that a hazard exists below and around the lights. They are red and should be visible all around and above the structure. Aerial obstruction lights are located on the topmost portion of any bridge considered by the Federal Aviation Administration (FAA) to present a hazard to aircraft. Depending on the bridge size, more than one light may be required.

Navigation Lighting

Navigation lights are used for the safe control of waterway traffic. The United States Coast Guard determines the requirements for the type, number, and placement of navigation lights on bridges. The lights are either green, red, or white and the specific application for each bridge site is unique.

Green lights usually indicate the center of a channel. These lights are placed at the bottom midspan of the superstructure. Red lights indicate the existence of an obstacle. When placed on the bottom of the superstructure, a red light indicates the limit of the channel. Lights placed to indicate a pier are placed on the pier near the waterline. Three white lights in a vertical fashion placed on the superstructure indicate the main channel.

Signs

Among the various types of signs to be encountered are signs indicating:

- Weight limit
- Vertical clearance
- Lateral clearance
- Narrow underpass
- Traffic regulatory and advisory

Weight Limit

Weight limit signs are very important since they indicate the maximum vehicle load that can safely use the bridge.

Vertical Clearance

Vertical clearance signs indicate the minimum vertical clearance for the structure. This clearance is measured at the most restrictive location within the traveling lanes.

Lateral Clearance

Lateral clearance signs indicate that the bridge width is less than the approach roadway width. Lateral clearance restrictions may be called out with a "Narrow Bridge" sign or with reflective stripe boards at the bridge.

Narrow Underpass

Narrow underpass signs indicate where the roadway narrows at an underpass or where there is a pier in the middle of the roadway. Striped hazard markings and reflective hazard markers should be placed on these abutment walls and pier edges. The approaching pavement should be appropriately marked to warn motorists of the hazard.

Traffic Regulatory and Advisory

Traffic regulatory and advisory signs indicate speed restrictions which are consistent with the bridge and roadway design. Additional traffic markers may be present to facilitate the safe and continuous flow of traffic.

5.4.3 Common Problems of Deck Joints, Drainage Systems, Lighting and Signs

Deck Joints

Common problems encountered when inspecting deck joints include the following:

- Debris and accumulation of dirt in deck joints and troughs under finger joints
- Corrosion on joints and their supports
- Damaged, torn, or missing joint seals due to snow plows, traffic, or debris buildup
- Spalled edges on joints without armor
- Spalled edges on joints due to misalignment of both sides of the joint
- Broken or misaligned fingers
- Leaking closed joint systems (or evidence of leaking)

Drainage Systems

Common problems encountered when inspecting drainage systems include the following:

- Debris buildup at inlet grate where water from the deck enters the drainage system
- Clogged or partially clogged deck drains and/or inlets
- Disconnected/clogged downspout piping
- Cracked or split pipes
- Loose or missing connections (from drain pipe below the deck to outlet pipe)
- Corrosion or section loss in metal pipes

Lighting and Signs

Common problems encountered when inspecting lighting and signs include the following:

- Lighting and signs obstructed from view due to tree growth or other signs
- Lighting and signs not present at bridge site
- Signs presently unacceptable or incorrect vertical or horizontal clearance
- Signs defaced or covered with graffiti
- Corrosion or section loss
- Loose or missing anchorages at supports
- Missing signs
- Lighting outages

5.4.4 Inspection Locations and Procedures for Deck Joints, Drainage Systems, Lighting and Signs

Deck Joints

The deck joints must allow for the expansion and contraction of the bridge deck and superstructure. The inspector must be aware of and record conditions that keep the deck joint from functioning properly.

There is not a separate item on the Structure Inventory and Appraisal (SI&A) sheet to code the serviceability of deck joints, and deck joint conditions are not considered in the rating of the bridge. However, it is important for the inspector to note their condition since deck joint problems are often related to problems elsewhere on the bridge.

The Element Level Inspection system, however, does rate deck joints. For a detailed description of deck joint condition states, see the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements and the evaluation section of this topic.

Deck joints should be inspected for:

- Dirt and debris accumulation
- Proper alignment
- Damage to seals and armored plates
- Indiscriminate overlays
- Joint supports

- Joint anchorage devices

Dirt and Debris Accumulation

Dirt and debris lodged in the joint may prevent normal expansion and contraction, causing cracking in the deck and backwall, and overstress in the bearings. In addition, as dirt and debris is continually driven into a joint, the joint material can eventually fail (see Figures 5.4.15 and 5.4.16).

Figure 5.4.15 Debris Lodged in a Sliding Plate Joint

Figure 5.4.16 Dirt in a Compression Seal Joint

Proper Alignment

Both sides of the joint should be at the same level with no vertical displacement between the two. On straight bridges, the joint opening should be parallel across the deck.

In a finger plate joint, the individual fingers should mesh together properly, and they should be in the same plane as the deck surface (see Figure 5.4.17).

Figure 5.4.17 Improper Vertical Alignment at a Finger Plate Joint

It is important that the relative movements of the joint are consistent with the temperature. During the coldest and the warmest times of the day, the air temperature and the superstructure temperature should be recorded, and the joint opening should be documented. Measurements should be taken at each curb line and the centerline of the roadway. Since heat causes expansion, the joint opening should be smallest when the temperature is greatest. The superstructure temperature can be taken by placing a surface temperature thermometer or the bulb of a standard thermometer against the superstructure member itself. The superstructure temperature is generally about 1.7 to 2.8 °C (3 to 5 ºF) lower than the air temperature.

Damage to Seals and Armored Plates

Damage from snow plows, traffic, and debris can cause the joint seals to be torn, pulled out of the anchorage, or removed altogether (see Figure 5.4.18). It can also cause damage to armored plates. Any of these conditions should be noted by the inspector. Also look for evidence of leakage through closed joints.

Figure 5.4.18 Failed Compression Seal

Indiscriminate Overlays

When new pavement is applied to a bridge, it is frequently placed over the deck joints with little or no regard for their ability to function properly. This occurs most frequently on small, local bridges. Transverse cracks in the pavement may be evidence that a joint has been covered by the indiscriminate application of new overlay, and the joint function may be severely impaired (see Figure 5.4.19).

Figure 5.4.19 Asphalt Wearing Surface over an Expansion Joint

Joint Supports

Where larger expansions and contractions must be accommodated, the joint may be fully or partially supported from beneath by transverse beams. These joint supports should be carefully inspected for proper function and for corrosion and section loss (see Figure 5.4.20).

Figure 5.4.20 Support System under a Finger Plate Joint

Joint Anchorage Devices

Deficiencies in joint anchorage devices are a common source of deck joint problems. Therefore, joint anchorage devices should be carefully inspected for proper function and for corrosion. The concrete area in which the joint anchorage device is cast should also be inspected for signs of deterioration. This area adjacent to the joint is known as the joint header.

Drainage Systems

A properly functioning drainage system removes water, and all hazards associated with it, from a structure. There is not a separate item on the SI&A Sheet to code the serviceability of drainage systems, and drainage system conditions are not considered in the rating of the bridge. However, it is important for the inspector to note their condition, since drainage system problems can eventually lead to structural problems.

The following drainage system elements should be inspected:

- Bridge deck cross slope and profile
- Grates
- Deck drains and inlets
- Drainage troughs
- Outlet pipes

Bridge Deck Cross Slope and Profile

The cross slope and profile should not prevent runoff from entering the deck drains and inlets. Adequate cross slope should be provided so that water runs off the bridge deck at a sufficient rate.

Grates

Grates should be clear of debris (e.g., plants and grass) and free to allow deck runoff to enter. Grates that are deteriorated, broken, or missing should be reported.

Deck Drains and Inlets

Deck drains and inlets must be of sufficient size and spacing to carry the runoff away from the structure effectively. Since runoff conditions can change due to development, these drainage elements should be carefully examined with each bridge inspection. Clogged deck drains lead to accelerated deck deterioration and the undesirable condition of standing water in the traffic lanes (see Figure 5.4.21).

Figure 5.4.21 Clogged Drainage Inlet

Drainage Troughs

Drainage troughs located under the joint should be carefully examined. A buildup of debris can accelerate the deterioration of the trough and allow water to drain onto structural members. If possible, use a shovel to clean as much debris as practical; report the remaining condition for appropriate maintenance work. Once cleaned, any holes found in the trough should be noted. Any evidence that indicates the trough is overflowing should also be mentioned (see Figure 5.4.22).

Figure 5.4.22 Drainage Trough with Debris Accumulation

Outlet Pipes

Outlet pipes carry runoff away from the structure. The outlet pipe may be a straight extension of the deck drain, in which case it should be long enough so that runoff is not discharged onto the structure. The outlet pipe may also be a series of pipes, called downspouting. This type of outlet pipe should be examined for split or disconnected pipes that may allow runoff to accelerate deterioration of the structure. Check the connections between the outlet pipes and substructure. If a pipe is embedded inside of a substructure unit such as a concrete pier wall, check for cracking, delamination, or other freeze-thaw damage to the substructure.

Lighting

All lights should be clearly visible. Verify that all lights are functioning and that they are not obstructed from view. Check for corrosion and collision damage to light supports. Verify that appropriate lighting is provided. Exercise caution against electrocution. The inspector should contact the maintenance department to de-energize the lighting.

Signs

Signs should be located sufficiently in advance of the structure to permit the driver adequate time to react. All signs should be clearly legible. Verify that signs have not been defaced and are not obstructed from view. Inspect for corrosion and collision damage to sign supports. Verify that appropriate signing is provided.

5.4.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of deck joints, drainage systems, lighting, and signs. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) component rating method and the AASHTO element level condition state assessment method.

Application of NBIS Rating Guidelines

Deck joints, drainage systems, lighting, and signs should not impact the deck rating, but their condition should be described in the inspection report. Deficiencies in deck joints, drainage systems, lighting, and signs should be placed on the maintenance sheet showing estimated quantities.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then reviewed for the expansion joint. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value.

In an element level condition state assessment of expansion joints, the AASHTO CoRe element is one of the following, depending on the type of joint:

Element No.	Description
300	Strip seal expansion joint
301	Pourable joint seal
302	Compression joint seal
303	Assembly joint seal (modular)
304	Open expansion joint

Individual states have the option to change or add element numbers. In the case of expansion joints, some states have added a miscellaneous expansion joint element number.

The unit quantity for these elements is in meters or feet, and the entire element must be placed in one of the three available condition states. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

Drainage systems, lighting, and signs have no separate element numbers. The condition of the drainage systems, lighting, and signs should, however, be noted on the inspection form.

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Section 5
Inspection and Evaluation of Decks

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Topic 5.5 Safety Features

5.5.1 Introduction

For the past 25 years, highway design has included a special emphasis on providing safe roadsides for errant vehicles that may leave the roadway. Obstacles or fixed object hazards have typically been removed from within a specified roadside recovery area. Whenever this has not been feasible (for example, at bridge waterway crossings), then safety features such as highway or bridge barrier systems have been provided to screen motorists from the hazards present (see Figure 5.5.1). Such barriers sometimes constitute fixed object hazards themselves, though hopefully of less severity than the hazard they screen.

Figure 5.5.1 Bridge Safety Feature

Purpose

The barriers on bridges and their approaches are typically intended to provide vehicular containment and prevent motorist penetration into the hazard being over-passed, such as a stream or under-passing roadway or railroad. Containment of an errant vehicle is a primary consideration, but survival of vehicle occupants is of equal concern. Thus the design of bridge railing systems and bridge approach guardrail systems is intended to first provide vehicular containment and redirection, but then to also prevent rollover, to minimize snagging and the possibility of vehicle spinout, and to provide smooth vehicular redirection parallel with the barrier system. In addition, the bridge railing and bridge approach guardrail systems must do all of this within tolerable deceleration limits for seat-belted occupants.

Four Basic Components

Barrier systems at bridges are composed of four basic components:

- Bridge railing
- Transition
- Approach guardrail system
- Approach guardrail end treatment

Bridge Railing

The function of bridge railing is to contain and redirect errant vehicles on the bridge. Many rails could conceivably do this, but the safety of the driver and redirection of the vehicle must be taken into account.

Transition

A transition occurs between the approach guardrail system and bridge railing. Its purpose is to provide both a structurally secure connection to the bridge end post and also a zone of gradual stiffening and strengthening of the more flexible approach guardrail system where it is connected with the rigid bridge railing. Stiffening is essential to prevent "pocketing" or "snagging" of a colliding vehicle just before the rigid bridge railing end.

Approach Guardrail System

The approach guardrail system is intended to screen motorists from the hazardous feature beneath the bridge as they are approaching the bridge. This approach guardrail screening is often extended in advance of the bridge so as to also screen motorists from any hazardous roadside features on the approach to the bridge (see Figure 5.5.3).

Approach guardrail must have adequate length and structural qualities to safely contain and redirect an impacting vehicle within tolerable deceleration limits. Redirection should be smooth, without snagging, and should minimize any tendency for vehicle rollover or subsequent secondary collision with other vehicles. Similar to bridge railing, approach guardrail systems must satisfy agency standards, which specify acceptable heights, materials, strengths, and geometric features.

Approach Guardrail End Treatment

The approach guardrail end treatment is the special traffic friendly anchorage of the approach guardrail system (see Figures 5.5.2 and 5.5.3). It is located at the end at which vehicles are approaching the bridge. Ground anchorage is essential for adequate performance of the guardrail system. Special end treatment is necessary in order to minimize its threat to motorists as another fixed object hazard within the roadside recovery area.

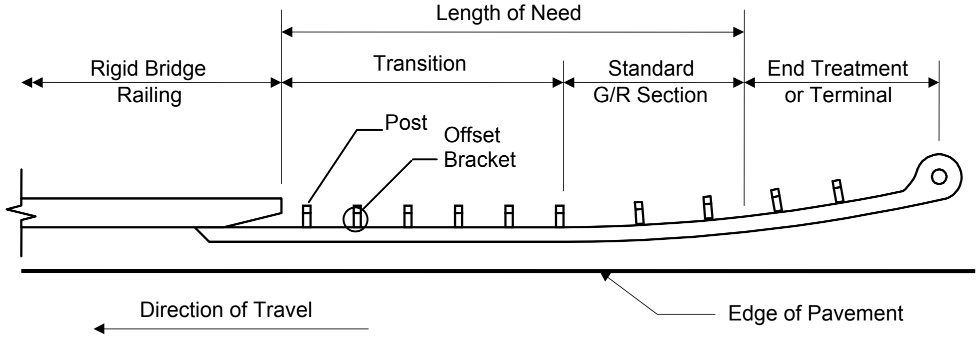

Figure 5.5.2 Approach Guardrail System

Figure 5.5.3 Approach Guardrail System

5.5.2 Evaluation

Each of the various elements of the bridge rail system is designed to meet a specific function. Based on items from an inspection checklist, the inspector can make a determination of whether or not these elements work as they should. The elements must pass the minimum standard criteria established by AASHTO.

Design Criteria

Until the mid 1980's, bridge railings were designed consistent with earlier precedent, the guidance provided in the AASHTO Standard Specifications for Highway Bridges, and professional judgment. The AASHTO Standard Specifications called for application of a 10-kip horizontally applied static load at key locations, and certain dimensional requirements were also specified. Full-scale crash testing was not required, although a design that "passed" such testing was also considered acceptable for use. Subsequent crash testing of several commonly used, statically designed bridge railings revealed unexpected failures of the systems. It was soon concluded that static design loadings were not sufficient to ensure adequate railing performance. As a result of these findings, the FHWA issued guidance in 1986 requiring that bridge railing systems must be (or must have been) successfully crash tested to be considered acceptable for use on Federal-aid projects.

Longitudinal roadside barriers, such as guardrail systems, had also been designed consistent with earlier precedent and judgment. Subsequent crash testing of these systems again revealed some unacceptable designs and prompted development of several new guardrail systems and details that were then identified as acceptable for new highway construction on Federal-aid projects.

Crash Test Criteria

Test requirements generally accepted at first were those contained in the National Cooperative Highway Research Program (NCHRP) Report 230 and in several earlier Transportation Research Board publications. In 1989, AASHTO published its “Guide Specifications for Bridge Railings,” wherein not only were the required tests specified but they were categorized into three separate performance levels. A warrant selection procedure was also included for determining an appropriate performance level for a given bridge site. As the crash test criteria differed in some respects from Report 230, use of the “Guide Specification” was, and continues to be, optional.

In 1990, the FHWA identified a number of crash-tested railing systems that met the requirements of NCHRP Report 230 or one of the performance levels in the AASHTO Guide Specifications. At this point, the FHWA considered that any railing that was acceptable based on Report 230 testing could also be considered acceptable for use, at least as a PL-1 (performance level 1) as described by the AASHTO Guide Specifications. They also stated that any SL-1 (service level 1) railing developed and reported in NCHRP Report 239, “Multiple-Service-Level Highway Bridge Railing Selection Procedures,” could be considered equivalent to a PL-1 railing.

In 1993, NCHRP Report 230 was superseded by NCHRP Report 350, “Recommended Procedures for the Safety Performance Evaluation of Highway Features.” Its current testing criteria include provisions for six different test levels, all of which differ in some ways from the previous Report 230 tests, as well as those in the AASHTO Guide Specifications. No selection procedures or warrants for the use of a specific test level are included in Report 350, although a separate research effort is underway to establish such warrants. Adding to the conflicting guidance for selection of an appropriate bridge railing system, the 1994 AASHTO LRFD Bridge Design Specifications have been issued as an alternate to the long-standing AASHTO Standard Specifications for Highway Bridges. This most recent bridge design specification contains recommendations on railing designs and crash testing which differ from both NCHRP Report 350 and the AASHTO Guide Specifications.

Current FHWA Policy

Bridge railings to be installed on National Highway System (NHS) projects must meet the acceptance criteria contained in NCHRP Report 350 or a recognized successor to those criteria. The minimum acceptable bridge railing for high-speed highways is a Test Level 3 (TL-3) unless supported by a rational selection procedure. For locations where the posted speed limit is less than 45 mph, a TL-2 bridge railing is considered acceptable.

Railings that have been found acceptable under the crash testing and acceptance criteria of NCHRP Report 230, the AASHTO Guide Specifications for Bridge Railings, or the AASHTO LRFD Bridge Design Specifications will be considered as meeting the requirements of NCHRP Report 350, provided they are equivalent to appropriate Report 350 Test Levels. This comparison of equivalencies has been tabulated by the FHWA in their May 30, 1997 memorandum on crash testing of bridge railings, with an attached May 14, 1996 document on bridge railing design and testing.

The FHWA continues to encourage support for development of railing test level selection procedures. In the interim, until AASHTO adopts a new railing test level selection procedure, the FHWA will accept the procedures in the AASHTO Guide Specifications or, as an alternate, a rational, experience-based, cost beneficial, consistently applied procedure proposed by an individual state. Their 1996 document includes a listing of railings considered acceptable under the NCHRP Report 350 guidelines or their presumed equivalent guidelines. New crash-tested railings continue to be approved and added, and their identity and features can be obtained from the FHWA.

For non-NHS projects, the setting of criteria for establishing acceptability for bridge railings has been relegated by the FHWA to the individual states. Some states require conformity with the FHWA's NHS criteria for all bridges, on any of the highway systems. In other states, lesser performance criteria are accepted for bridges on non-NHS roads, so there may be variations between states as to safety feature acceptability.

Railing Evaluation Results/Resources

The FHWA maintains a website, http://safety.fhwa.dot.gov/programs/road-side_hardware.htm which, identifies all of the bridge and longitudinal roadside barrier systems, transitions, and end treatments which have been found to meet the various crash test requirements of NCHRP Reports 350 and 230. The website includes acceptance letters as well as links to manufacturers' websites for information on proprietary systems. Listings for several categories of safety features are accessible. New listings of bridge barriers more recently tested may be found on the longitudinal barrier list so a thorough search of all listings is advisable to identify a specific feature and its test results. The May 30, 1997 memorandum and its attached document with test level equivalencies can also be found on the website.

Additional information can also be found in the current AASHTO "Roadside Design Guide" and in the current AASHTO-AGC-ARTBA Report, "A Guide to Standardized Highway Barrier Hardware."

5.5.3 Identification and Appraisal

Identification of conforming and non-conforming bridge safety features will vary depending upon highway classification and the jurisdiction involved. With various acceptance criteria to consider and with continuing crash testing and approvals of new barriers, it is advisable to rely on the most current specific acceptance criteria for the particular state or jurisdiction within which a bridge is located. A listing of currently conforming versus non-conforming bridge safety features should be obtained for each jurisdiction prior to identification and appraisal of these features in the course of bridge inspections within that jurisdiction.

Appraisal Coding

The FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*) requires an evaluation and reporting as to whether each of the four basic components satisfactorily conform to current safety design criteria for the respective component.

The condition of the safety features is not considered in the appraisal, but should be well documented in the inspection report. After determining whether the safety features at the site are acceptable, the inspector should assign an appraisal code. The FHWA *Coding Guide* contains four entries for safety features: one each for the bridge railing, approach guardrail, transition, and end treatment.

After making the determination as to whether or not safety features at the site meet currently acceptable standards, the inspector assigns an appraisal code of either 1 (meets) or 0 (does not meet) for each element of Item 36 (page 17, FHWA *Coding Guide*:

36A Bridge railing system
36B Approach guardrail transition
36C Approach guardrail system type
36D Guardrail end treatment

While there is only one safety features coding for each element, there are at least two bridge railings and four approach guardrail treatments. Some states have modified and set different coding standards. Therefore, the bridge inspector should code the worst condition for each element even though they may occur at different locations on the bridge.

Bridge Railings

Some examples of currently conforming concrete bridge railings for NHS roadways include 32" high New Jersey shape barrier, the concrete "F" shape, and the single slope concrete barrier (see Figures 5.5.4 and 5.5.5). Some steel post and beam railings mounted on a low curb, such as the Wyoming 2-tube steel railing (see Figure 5.5.6) also conforms, as do some combination safety shape barriers with a metal railing mounted on top. Safety shape barriers with a metal railing must not have a safety-walk in front of the railing. All bridge railings must pass current crash test requirements.

Figure 5.5.4 New Jersey Barrier

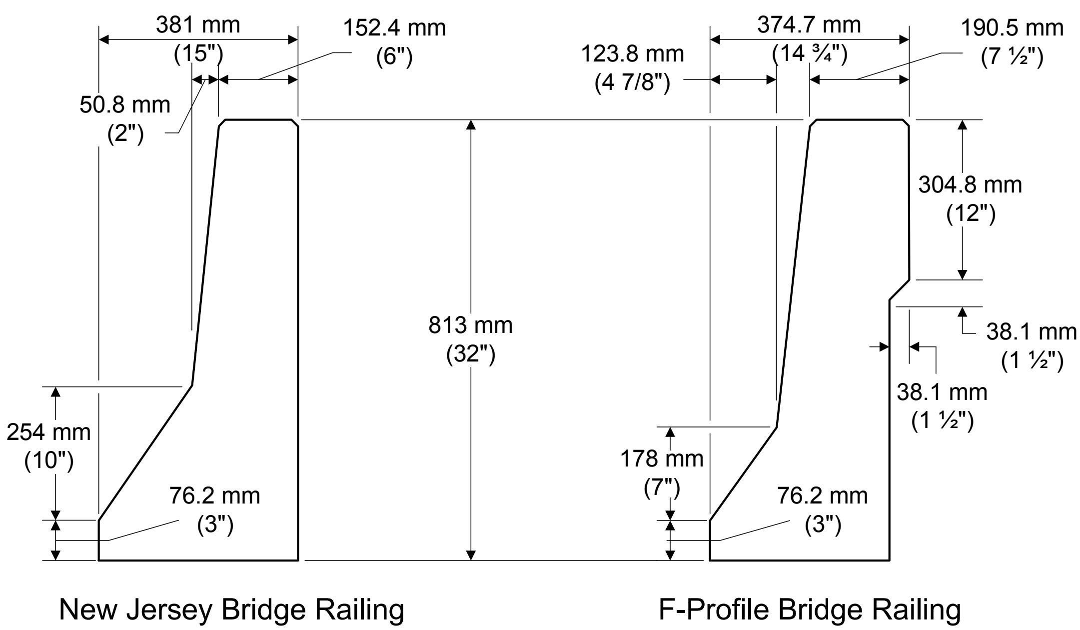

Figure 5.5.5 Comparison of New Jersey and “F” Shape

Figure 5.5.6 Wyoming 2-Tube Steel Railing

Transitions

A number of transitions between approach guardrail system and bridge railing were tested successfully using NCHRP Report 230 test criteria (see Figure 5.5.7). These are all illustrated schematically in the AASHTO "Roadside Design Guide." Though tested under NCHRP Report 230, the FHWA currently considers these as conforming transitions, at least until October 2002.

Figure 5.5.7 Thrie-beam System

Transition stiffening is usually accomplished through use of:

- Decreased post spacing
- Increased post size
- Embedment of posts in concrete bases
- Increased rail thickness, using a thicker gage rail element or by nesting two layers

Vehicle snagging is discouraged by providing an increased rail surface projection with either a broader rail face (e.g., thrie beam) or a rub rail being placed beneath the primary rail, to minimize both guardrail post and bridge endpost exposure as potential snag points.

Older transitions usually have some of the essential features but are often lacking in some. There may be guardrail anchorage to the bridge but insufficient stiffening, or perhaps some degree of stiffening but insufficient concealment of potential snag points such as the front corner of the bridge endpost or exposed guardrail posts. Cable connections to the bridge railing do not meet minimum criteria because they do not provide a smooth stiffened transition. Timber approach rail attached to the bridge rail is not an acceptable transition. No transition is provided at all when the bridge railing and approach guardrail are not structurally connected. Bridge railing and approach guardrail that do not in themselves meet minimum criteria will surely not have a transition that is adequate.

Approach Guardrail Systems

The FHWA's February 14, 2000 memo to Resource Centers summarizes the non-proprietary longitudinal barrier systems that are currently considered to meet NCHRP Report 350 guidelines. The strong post (steel or wood) W-beam guardrails with wood or approved plastic blocks are examples at Test Level 3, as are the strong post thrie-beam systems (see Figure 5.5.8). The same W-beam barriers used with a steel block are included at Test Level 2.

Figure 5.5.8 Thrie-beam System

Post and cable systems do not meet minimum criteria for bridge approach guardrail systems because they allow both snagging and pocketing of a vehicle upon impact. Timber approach guardrail does not meet minimum criteria for strength, continuity, or performance.

Approach Guardrail End Treatment

A variety of guardrail end treatments have been approved for use by the FHWA. The specific installation is dependent on various roadway features and testimony procedures as administered by the National Cooperative Highway Research Program (NCHRP). Current listings of crash tested end treatments and documentation of their performance can be found at http://safety.fhwa.dot.gov/fourthlevel/pro_res_road_nchrp350.htm. Probably the most universally effective is the buried-in-back-slope treatment where the longitudinal barrier is introduced from a buried anchorage, typically from a cut slope preceding the bridge approach guardrail installation (see Figure 5.5.9). Essential for these installations are keeping a constant rail height relative to the roadway grade and then provision of both a rub rail and an anchorage capable of developing the full strength of the W-beam rail.

Figure 5.5.9 W-Shaped Guardrail End Flared and Buried into an Embankment

Several modern proprietary end treatments that are currently in use, include:

- Sequential Kinking Terminal (SKT-350, Road Systems, Inc.)
- Extruder Terminal (ET-2000)
- Crash-cushion Attenuating Terminal (CAT-350, Trinity Industries)
- FLared Energy-Absorbing Terminal (FLEAT-350, Road Systems, Inc.) (see Figure 5.5.10).
- Slotted Rail Terminal (SRT-350) (see Figure 5.5.11)
- Improved slotted rail terminal (ROSS) – a modification of the slotted rail terminal
- Modified Eccentric Loads Terminal (MELT) (see Figure 5.5.13)

Figure 5.5.10 FLEAT-350 - FLared Energy-Absorbing Terminal

Figure 5.5.11 SRT-350 - Slotted Rail Terminal

Figure 5.5.12 TAU-II Redirective, Non-Gating Crash Cushion

Flaring the guardrail end to reduce the likelihood of a vehicular impact is only effective if there is enough space for a substantial flare from the edge of traveled way.

Burying the guardrail end has been used with and without flaring. If the guardrail end is turned down for burying, it has frequently produced rollover accidents and is not currently considered an acceptable end treatment.

If the end is concealed by flaring without turning down, and then burying at full height in a cut slope, the method has proven effective at preventing end impacts.

One of several breakaway treatments can be used. The guardrail end is modified to permit safe penetration through the system for end impacts, yet effective redirection of vehicles for impacts slightly after of the end treatment.

One of the most familiar and long-used breakaway end treatments is the BCT or breakaway cable terminal. This end treatment must also be flared to be safely effective. Flaring, along with blunting of the rail end serve to facilitate a buckling of the rail element rather than vehicle impalement. Two weakened timber posts are breakaway to minimize deceleration forces upon direct impact with either post. Cable anchorage of the rail is provided to assure adequate anchorage of the system for possible impacts after of the end treatment.

A newer version of the BCT called the MELT, for modified eccentric loader terminal, provides improved breakaway performance, especially for smaller vehicles (see Figure 5.5.13). An eccentric loader and buffer stiffening are employed to assure deflection of the rail without impaling, and a load-distributing strut between the first two breakaway timber posts enhances rail anchorage capability.

Figure 5.5.13 MELT - Modified Eccentric Loads Terminal

Other newer breakaway or energy-absorbing end treatments include the ET 2000 extruder terminal, a proven end treatment which, when impacted, slides down the rail causing diversion of the W-beam rail element through a flattening or extruding fitting (see Figure 5.5.14). As the rail is threaded through and flattened out by the extruder, impact energy is expended. The flattened rail element is peeled back out of the way as vehicle energy is transferred and gradual deceleration occurs. This end treatment is designed for use without flaring.

Figure 5.5.14 ET 2000 - Extruder Terminal

The CAT or crash-cushion attenuating terminal progressively collapses with perforated W-beam rails telescoping as the system safely decelerates an impacting vehicle (see Figure 5.5.15). Crash energy is attenuated in the process. Breakaway timber posts are employed and the treatment does not have to be flared. This makes it a feasible end treatment for guardrail introduction when there is insufficient roadside space for flaring.

Figure 5.5.15 CAT – Crash-cushion Attenuating Terminal

The SENTRE guardrail end treatment is another telescoping terminal, which utilizes posts with slip bases for breakaway and sand-filled boxes to gradually decelerate and gently guide an impacting vehicle away from the fixed rail hazard (see Figure 5.5.16). All major components are reusable which makes the system more economical for locations where more frequent impacts are expected. Flaring is possible but not required.

Figure 5.5.16 SENTRE End Treatment

The TREND dual purpose end treatment has similar features with reusable telescoping rail panels, redirecting cable, breakaway slip base posts, and replaceable sand-filled boxes (see Figure 5.5.17). However, the system is unique in that it is designed to also serve in a dual role as a transition connection to a rigid bridge railing. It is not designed to be flared.

Figure 5.5.17 TREND End Treatment

The last method for railing end treatment is shielding of the barrier with an energy-absorbing or attenuating system which dissipates impact energy as an impacting vehicle is gradually brought to a stop before reaching a rigid bridge rail endpost. Though vehicle damage may be severe, deceleration is controlled within tolerable limits to minimize occupant injury.

A variety of impact attenuators have been used, including expendable sand-filled containers, which shatter and absorb energy during impacts.

There are also more elaborate telescoping fender systems, which redirect side impacts but also telescope and attenuate crash energy through crushing of replaceable foam-filled cartridges for direct impacts. Older versions absorbed energy through expulsion of water from water-filled tubes as the device collapsed. Most parts for these more elaborate devices are reusable, making them very suitable for bridge rail end locations where frequent impacts might be expected.

In certain cases, such as at the trailing end of a one-way bridge, guardrail is not required at all.

The type of end treatment, which has sometimes been called a boxing glove, is not an acceptable end treatment.

5.5.4 Median Barriers

Median barriers are used to separate opposing traffic lanes when the average daily traffic (ADT) on the road exceeds a specified amount. They are usually found on high speed, limited access highways.

The most commonly used median barrier on bridges is the concrete median barrier. This is a double sided parapet, and it should meet the current criteria for the crash testing of bridge railing. The only acceptable end treatment for a concrete median barrier is an impact attenuator.

Double-faced steel W-beam or thrie beam railing on standard heavy posts are also used for median barriers.

Inspection of Median Barriers

Median barriers should be firmly attached to the deck, and they should be functional. Inspect for collision damage and attachment to any additional safety features. Check for deterioration and spalling on concrete median barriers, and examine for corrosion on steel railings and posts.

5.5.5 Safety Feature Inspection

The inspection of bridge safety features involves evaluation of the bridge railing system on the bridge, the guardrail system leading from the bridge, the guardrail system leading from the approach roadway to the bridge end, and whether these two systems will likely function acceptably together to safely contain and redirect errant vehicles which may collide with them.

Inspection

Criteria that must be considered during the inspection of the bridge railing are the height, material, strength, geometric features, and the likelihood of acceptable crash test performance.

Many state agencies have developed their own acceptance guidelines for bridge railings. The inspector should be familiar with agency guidelines for his or her state.

Bridge Railing

The following should be inspected on a bridge railing:

- Metal bridge railings should be firmly attached to the deck and should be functional. Check especially for corrosion and collision damage, which might render these railings ineffective (see Figure 5.5.18). Comparison of existing metal railing systems with approved crash-tested designs will establish their acceptability and crash worthiness.

Figure 5.5.18 Damaged Steel Post Bridge Railing

- Concrete bridge railing is generally cast-in-place and engages reinforcing bars to develop structural anchorage in the deck slab. Verify that the concrete is sound and that reinforcing bars are not exposed.

A commonly used bridge railing is the New Jersey parapet or safety shape.

If add-on rails are other than decorative or for pedestrians, their structural adequacy can again be verified by comparison with successfully crash tested designs.

Approach Guardrail

The following should be inspected on an approach guardrail:

- The inspector should verify that agency standards are met.
- Make note of rail element type, post size and post spacing for comparison with approved designs to verify acceptability of the guardrail system.
- Document any significant collision damage, which is evident (see Figure 5.5.19).
- Note any deterioration of guardrail elements, which could weaken the system.
- Note any areas where the railing may "pocket" during impact, snagging the vehicle and causing an abrupt deceleration or erratic rebound.
- Loose or missing bolts should also be noted.

Unless specifically designed for impact, timber approach guardrail does not meet minimum criteria for strength.

Figure 5.5.19 Approach Guardrail Collision Damage

Transition

The following should be inspected on a transition:

- Check the approach guardrail transition to the bridge railing for adequate structural anchorage to the bridge railing system.

- Check for sufficiently reduced post spacing to assure stiffening of the guardrail at the approach to the rigid bridge rail end.

- Check for smooth transition details to minimize the possibility of snagging an impacting vehicle, causing excessive deceleration.

Timber should not be used for the rails in transitions.

End Treatment

Note the type, condition, and suitability of any end treatment. Acceptable crash-tested end treatments are identified in the AASHTO Roadside Design Guide or with current FHWA issuances.

End treatments may not be required on the trailing end of a one-way bridge.

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Section 6

Inspection and Evaluation of Common Timber Superstructures

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Section 6

Inspection and Evaluation of Common Timber Superstructures

Topic 6.1 Solid Sawn Timber Bridges

6.1.1 Introduction

Timber bridges are gaining a resurgence in popularity throughout the United States. There are two basic classifications in timber construction: solid sawn and glued-laminated (glulam). A solid sawn beam is a section of tree cut to the desired size at a saw mill. Solid sawn multi-beam bridges are the simplest type of timber bridge (see Figure 6.1.1).

Figure 6.1.1 Elevation View of a Solid Sawn Multi-Beam Bridge

6.1.2 Design Characteristics

Multi-beam Bridges

Solid sawn multi-beam bridges consist of multiple solid sawn beams spanning between substructure units (see Figure 6.1.2). The deck is typically comprised of transversely laid timber planks, which are supported by the beams, and longitudinally laid planks called runners, on which the vehicles ride. Sometimes a bituminous wearing surface is placed on the deck planks to provide a skid resistant riding surface for vehicles, as well as a protective surface for the planks. Beam sizes typically range from about 150 mm by 300 mm (6 inches by 12 inches) to 200 mm by 400 mm (8 inches by 16 inches), and the beams are usually spaced about 600 mm (24 inches) on center.

Figure 6.1.2 Underside View of a Solid Sawn Multi-Beam Bridge

This bridge type is generally used in older, shorter span bridges, spanning up to about 8 m (25 feet). Shorter spans are sometimes combined to form longer multiple span bridges and trestles. Many older timber trestles were built for railroads and trolley lines. Solid sawn timbers have become obsolete for most modern bridge members due to the development of high quality glulam members (see Topic 6.2).

Covered Bridges

Covered bridges are generally found along rural roads and get their name from the fact that walls and a roof protect the bridge superstructure. They are usually owned by local municipalities, although some are owned by states or private individuals. Some still carry highway traffic, but many are only open to pedestrians. While most covered bridges were built during the 1800's and early 1900's, there are a number of covered bridges being built today as historic reconstruction projects (see Figures 6.1.3 and 6.1.4).

Figure 6.1.3 Elevation View of Covered Bridge

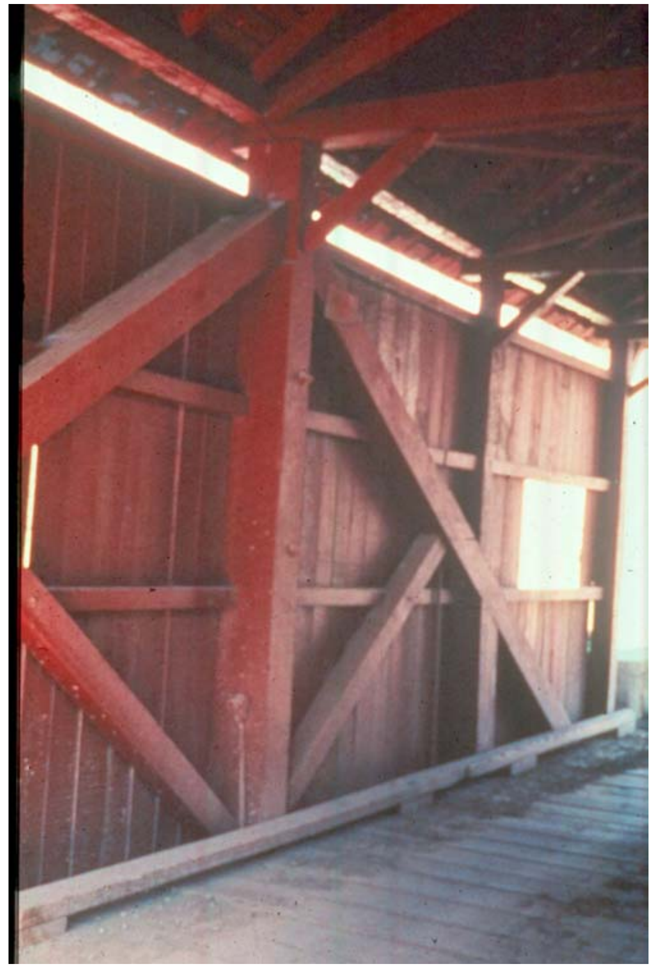

Figure 6.1.4 Inside View of Covered Bridge Showing King Post Truss Design

Trusses

The majority of covered bridges are essentially truss bridges (see Figure 6.1.5). Solid sawn timber members make up the trusses of these historic structures. The covers on the bridges prevent decay of the truss and undoubtedly are responsible for their longevity. Typical truss types for covered bridges include the king post, queen post, Town, Warren, and Howe (see Figure 6.1.6). The floor system consists of timber deck planks, stringers, and floorbeams. The span lengths of covered bridges are generally in the range of 15 to 30 m (50 to 100 feet), although many are well over 30 m (100 feet) and some span over 61 m (200 feet)).

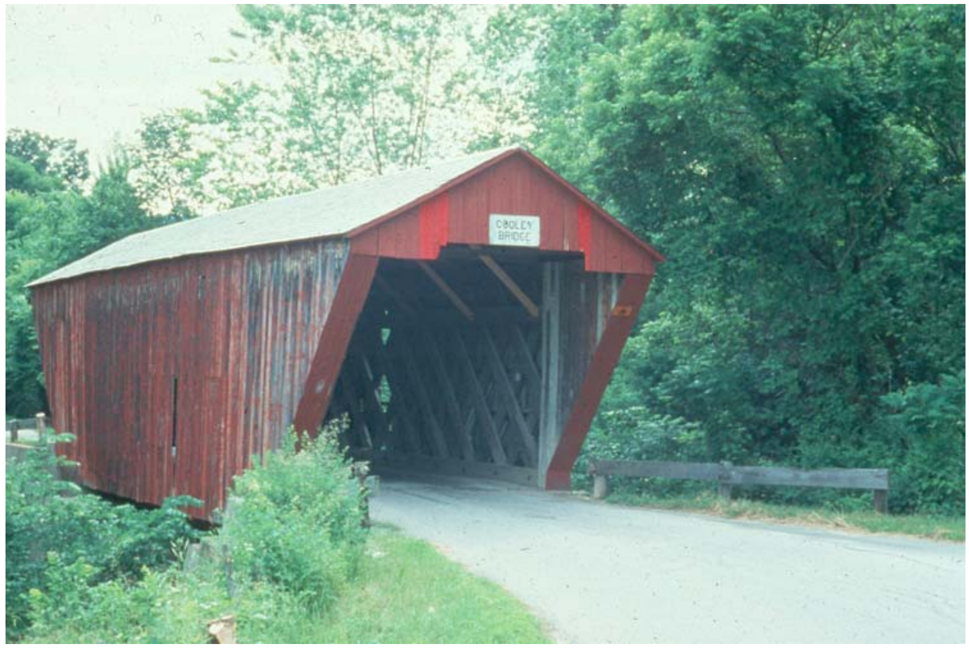

Figure 6.1.5 Town Truss Covered Bridge

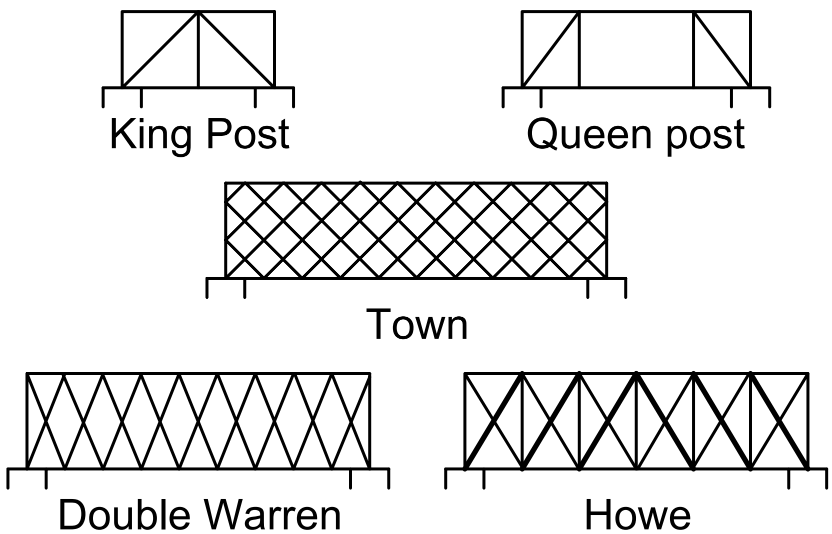

Figure 6.1.6 Common Covered Bridge Trusses

Arches

Timber arches were first used in covered bridges by Theodore Burr to strengthen the series of truss configurations normally used in covered bridges. These became known as Burr arch-trusses (see Figures 6.1.7, 6.1.8 and 6.1.9). The arch served as the main supporting element, and the king posts simply strengthened the arch. Because of their greater strength, many of these structures still exist today.

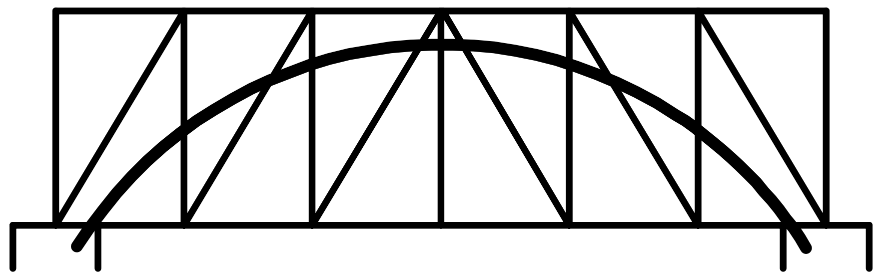

Figure 6.1.7 Schematic of Burr Arch-truss Covered Bridge

Figure 6.1.8 Burr Arch-truss Covered Bridge

Figure 6.1.9 Inside View of Covered Bridge with Burr Arch-truss Design

Primary and Secondary Members

The primary members of solid sawn multi-beam bridges are the beams, and the secondary members are the diaphragms or cross bracing if present (see Figure 6.1.2). These bridges usually have timber diaphragms or cross bracing between beams at several locations along the span.

The primary members in truss and arch structures are the truss members (chords, diagonals, and verticals), arch ribs, stringers, and floorbeams (see Figure 6.1.10). The secondary members are the diaphragms and cross bracing between stringers, the upper and lower lateral bracing, sway bracing, and the covers on the roof and sides when present.

Figure 6.1.10 Town Truss Design

6.1.3 Overview of Common Defects

Common defects that occur on solid sawn timber beams include:

- Checks, splits, and shakes
- Decay by fungi
- Damage by insects and borers
- Damage from impact/collisions
- Damage from abrasion/wear
- Damage from weathering/warping
- Damage from overstress

Other less common defects that may be encountered by the inspector include damage from chemical attack and damage from fire, which can be very destructive to timber structures. Refer to Topic 2.1 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

6.1.4 Inspection Procedures and Locations

Procedures

Advanced Inspection Techniques

In addition, several advanced techniques are available for timber inspection.

Nondestructive methods, described in Topic 13.1.2, include:

- Pol-Tek
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 13.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Shigometer

Locations

Bearing Areas

Check the bearing areas for crushing of the beams near the bearing seat (see Figure 6.1.11). Investigate for decay and insect damage by visual inspection and sounding and/or probing at the ends of the beams where dirt, debris, and moisture tend to accumulate. Also verify the condition and operation of the bearing devices, if they are present (refer to Topic 9.1).

Figure 6.1.11 Bearing Area of Typical Solid Sawn Beam

Shear Zones

As discussed in Topic P.1, maximum shear occurs near supports. A horizontal shear force of equal magnitude accompanies the vertical shear component of this force. Because of timber's orthotropic cell structure, it has excellent resistance against vertical shear but low resistance against horizontal shear. The failure of a solid sawn timber member due to load is generally preceded by horizontal shear cracking along the grain. A horizontal shear "crack" is effectively a longitudinal split.

Investigate the area near the supports for the presence of horizontal shear cracking. The zones of maximum shear are at the ends of the beam. The presence of transverse cracks on the underside of the girders or horizontal cracks on the sides of the girders indicate the onset of shear failure. These cracks can propagate quickly toward midspan and represent lost moment capacity of up to 75%. (see Figure 6.1.12). Measure these cracks carefully for length and width width.

Figure 6.1.12 Horizontal Shear Crack in a Timber Beam

Tension Zones

Examine the zones of maximum tension for signs of structural distress. The maximum tension generally occurs at the bottom half of the middle third of the beam span. Investigate for section loss due to decay or fire, especially near mid-span and at the ends. Examine beams for excessive deflection or sagging. Tension cracks in timber break the cell structure perpendicular to the grain and are typically preceded by the appearance of horizontal shear cracks.

Solid sawn beams with sloping grain that intersects the surface in the tension zone are particularly susceptible to flexure cracking. This is because the tensile stress and horizontal shear stress combine to split the grain apart.

Areas Exposed to Drainage

Timber bridges with open plank decks are exposed throughout. Plank decks with asphalt overlays in good condition offer some protection. In these cases, deck joint areas at span ends are candidates for drainage exposure.

Investigate for signs of decay along the full length of the beam but especially where the beam is subjected to continual wetness and areas that trap moisture. These include member interfaces between deck planks and stringers, deck planks and beams, beams and bearing seats, stringers and floorbeams, floorbeams and trusses, truss member connections, arch connections, and all fastener locations. (see Figure 6.1.13).

Decay and chemical attack may be evidenced by discolored wood, brown and white rot, the formation of fruiting bodies (the result of fungal attacks, which produce disc-shaped bodies that distribute reproductive spores), “sunken” faces in the wood, or soft “punky” texture of the wood. When surface probing for expected decay is inconclusive, the next step is to drill the suspect area. If this has been done in a previous inspection, the drill hole area should be examined carefully for proper preservation treatment and dowel plug installations.

Figure 6.1.13 Decay in a Timber Beam

Areas of Insect Infestation

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Further probing or drilling should be performed in suspect areas.

Areas Exposed to Traffic

For overhead and through structures, check for collision damage from vehicles passing below or adjacent to structural members.

Previous Repairs

Thoroughly examine any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

Secondary Members

Inspect bracing members for decay and fire damage. Examine connections of bracing to beams for tightness, cracked or split members, and corroded, loose, or missing fasteners (see Figure 6.1.14).

Figure 6.1.14 Typical Timber End Diaphragm

Fasteners and Connectors

Check all fasteners (e.g., nails, screws, bolts, and deck clips) for corrosion. Also inspect for loose or missing fasteners.

6.1.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of timber bridges. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about the NBIS rating guidelines.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the superstructure. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Smart Flags are also used to describe the condition of timber bridges.

In an element level condition state assessment of a solid sawn timber bridge, the AASHTO CoRe elements are:

Element No.	**Description**
111	Open Girder/Beam
117	Stringer
135	Truss/Arch
156	Floorbeam

The unit quantity for the timber superstructures is in meters or feet, and the total length must be placed in one of the available condition states. Condition state 1 is the best possible rating. See Topic 4.6 for condition state descriptions.

For damage due to traffic impact, the “Traffic Impact” Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

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Section 6

Inspection and Evaluation of Common Timber Superstructures

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Topic 6.2 Glulam Timber Bridges

6.2.1 Introduction

A glued-laminated (glulam) member is made by gluing strips of wood together to form a structural member of the desired size. An advantage of glulam members is that they allow for a higher utilization of the wood, since a lower grade of material can be used in of lower stress. Many strength reducing characteristics of wood, such as knots and checks, are minimized due to relatively small laminate dimensions. Also, the size and length of a glulam member is not limited by the size or length of a tree. Strips of wood used in glulam members are generally 20 to 40 mm (3/4 to 1-1/2 inches) thick (see Figures 6.2.1 and 6.2.2).

Figure 6.2.1 Elevation View of a Glulam Multi-beam Bridge

Figure 6.2.2 Underside View of a Glulam Multi-beam Bridge

6.2.2 Design Characteristics

Multi-beam Bridges

Glulam multi-beam bridges are very similar to solid sawn multi-beam bridges, but they generally use larger members to span greater distances. Glulam multi-beam bridges are typically simple span designs (see Figure 6.2.3). They usually support a deck consisting of glulam panels with a bituminous wearing surface. Beam sizes typically range from about 150 mm by 610 mm (6 inches by 24 inches) to 310 mm by 1525 mm (12-1/4 inches by 60 inches), and the beams are usually spaced 1.7 m to 2.0 m (5-1/2 feet to 6-1/2 feet) on center (see Figure 6.2.4).

These more modern multi-beam bridges can typically be used in spans of up to 24 m (80 feet), although some span as long as 46 m (150 feet). These too can be used to form longer multiple span structures. They are generally found on local and secondary roads, as well as in park settings.

Figure 6.2.3 Elevation View of Typical Glulam Multi-beam Bridge

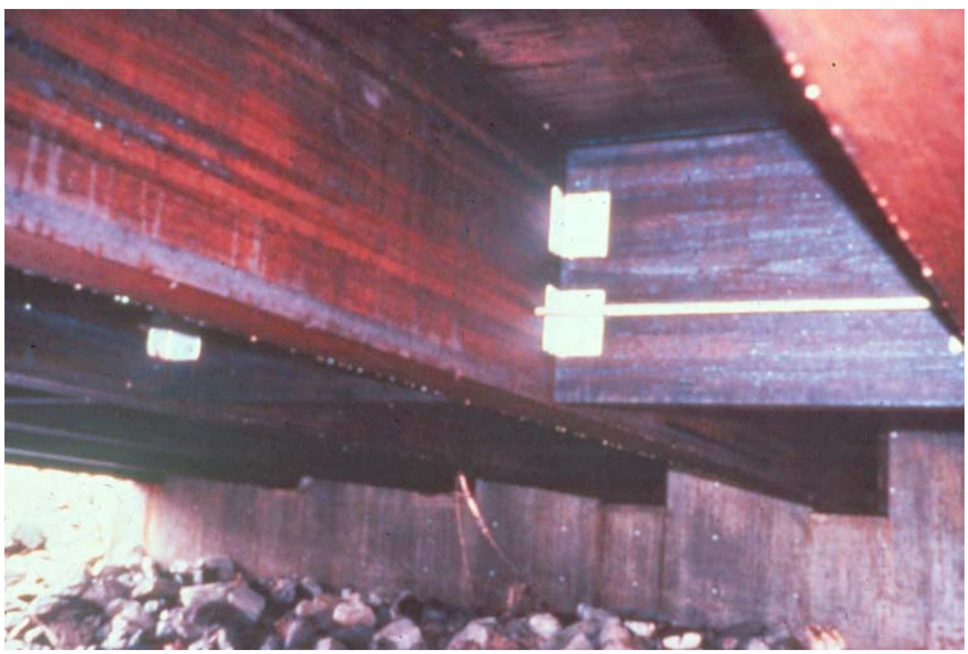

Figure 6.2.4 Underside View of Typical Glulam Multi-beam Bridge

Truss Bridges

Trusses may be of the through-type or of the deck-type. Usually the floor system consists of a timber deck supported by timber stringers and floorbeams, all of which are supported by the trusses (see Figures 6.2.5 and 6.2.6). Timber trusses are generally used for spans that are not economically feasible for timber multi-beam bridges. Timber trusses are practical for spans that range from 46 to 76 m (150 to 250 feet) (see Figure 6.2.7).

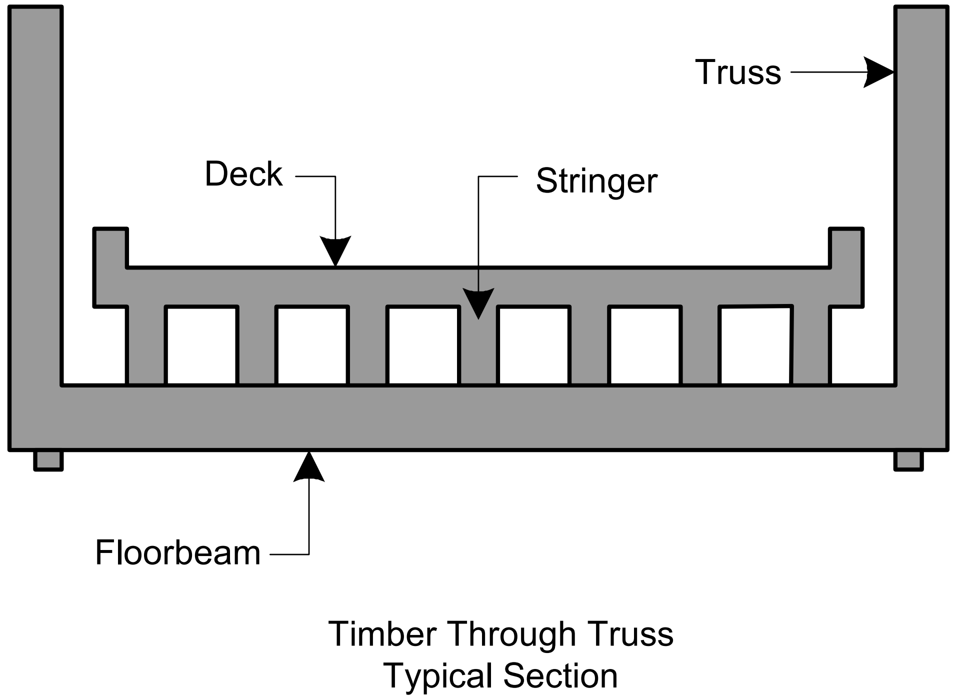

Figure 6.2.5 Timber Through Truss Typical Section

Figure 6.2.6 Bowstring Truss Pedestrian Bridge

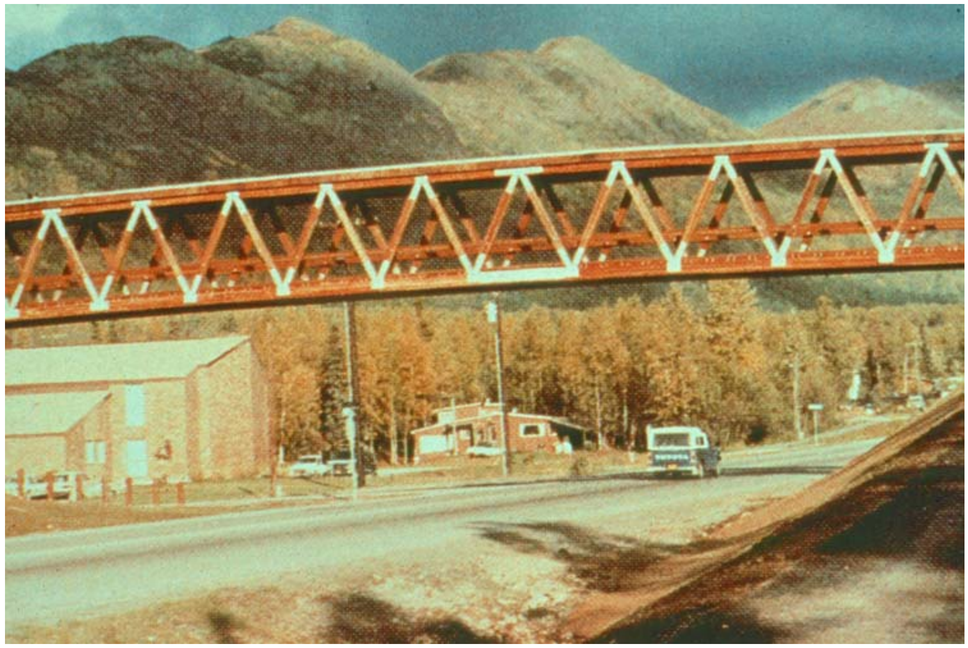

Figure 6.2.7 Parallel Chord Truss Pedestrian Bridge (Eagle River, Alaska)

Arch Bridges

Glulam arch bridges usually consist of two- or three-hinged deck arches, which support a glulam deck and floor system (see Figures 6.2.8 and 6.2.9). Glulam arches are practical for spans of up to about 91 m (300 feet). Although they are not widely used for highway bridges, they are frequently used for pedestrian overpasses and in locations such as parks where aesthetics is important.

Figure 6.2.8 Glulam Arch Bridge over Glulam Multi-beam Bridge (Keystone Wye interchange, South Dakota)

Figure 6.2.9 Glulam Arch Bridge (Colorado)

Primary and Secondary Members

The primary members of glulam multi-beam bridges are the beams, and the secondary members are the diaphragms or cross bracing (see Figures 6.2.10 and 6.2.11). Due to the larger depth of the glulam beams, diaphragms or cross bracing should always be present. Diaphragms are usually constructed of short glulam members, and cross bracing is usually constructed of steel angles.

The primary members of glulam arch and truss structures are the arch, truss, stringers, and floorbeams and spandrel bents. The secondary members are the diaphragms and cross bracing between the stringers and the lateral bracing between the arch or truss.

Figure 6.2.10 Elevation View of Typical Glulam Beam

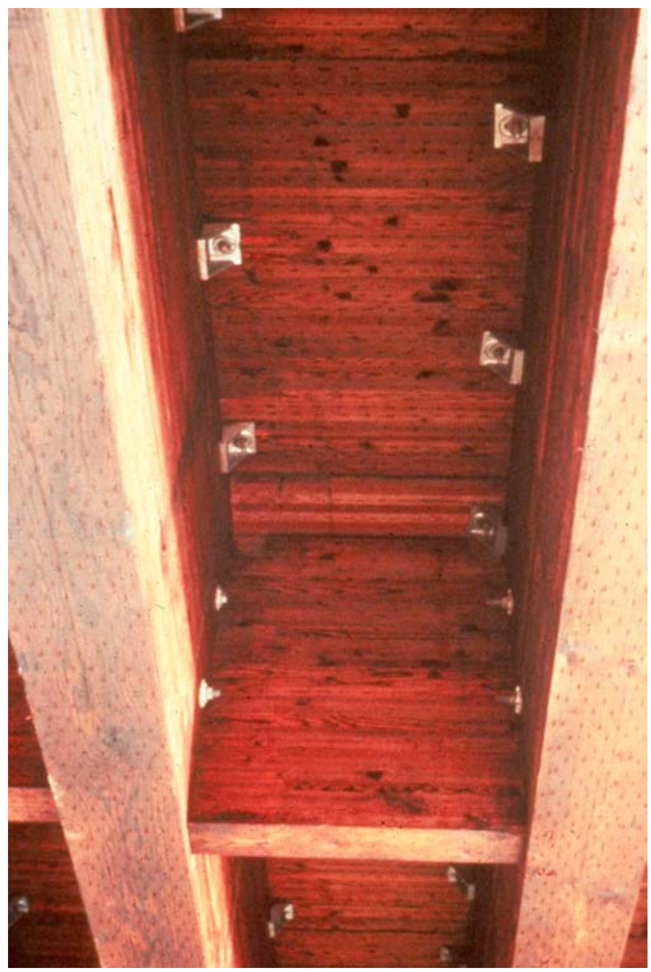

Figure 6.2.11 Typical Glulam Diaphragm

Recent technology has also produced glulam timber materials which are reinforced with fibers such as aramids, carbon, and fiberglass. These fiber reinforced glulam beams help increase the strength and mechanical properties of timber bridges.

6.2.3 Overview of Common Defects

Common defects that occur on glulam timber beams include:

- Checks, splits, and shakes
- Decay by fungi
- Damage by insects and borers
- Damage from impact/collisions
- Damage from abrasion/wear
- Damage from weathering/warping
- Damage from overstress

Other less common defects that may be encountered by the inspector include damage from chemical attack and damage from fire, which can be very destructive to timber structures. Refer to Topic 2.1 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

6.2.4 Inspection Procedures and Locations

Since these superstructures are very similar to solid sawn superstructures, the inspection locations and procedures for glulam bridges are virtually the same as those for solid sawn bridges.

Procedures

Visual

The inspection of splits, cracks, shakes, fungus decay, deflections, crushing, delaminations, and loose connections is primarily a visual activity.

Physical

The physical examination of a glulam member can be conducted with a hammer or pick. The hammer is used to sound the members to detect hollow areas or internal decay. Picks are used to determine the condition of the surface

Advanced Inspection Techniques

In addition, several advanced techniques are available for timber inspection. Nondestructive methods, described in Topic 13.1.2, include:

- Pol-Tek
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 13.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Shigometer

Locations

Bearing Areas

Inspect the bearing areas for crushing of the beams (see Figure 6.2.12). Investigate for decay and insect damage by visual inspection, sounding, and/or probing at the ends of the beams. Also check the condition and operation of the bearing devices if they are present (refer to Topic 9.1).

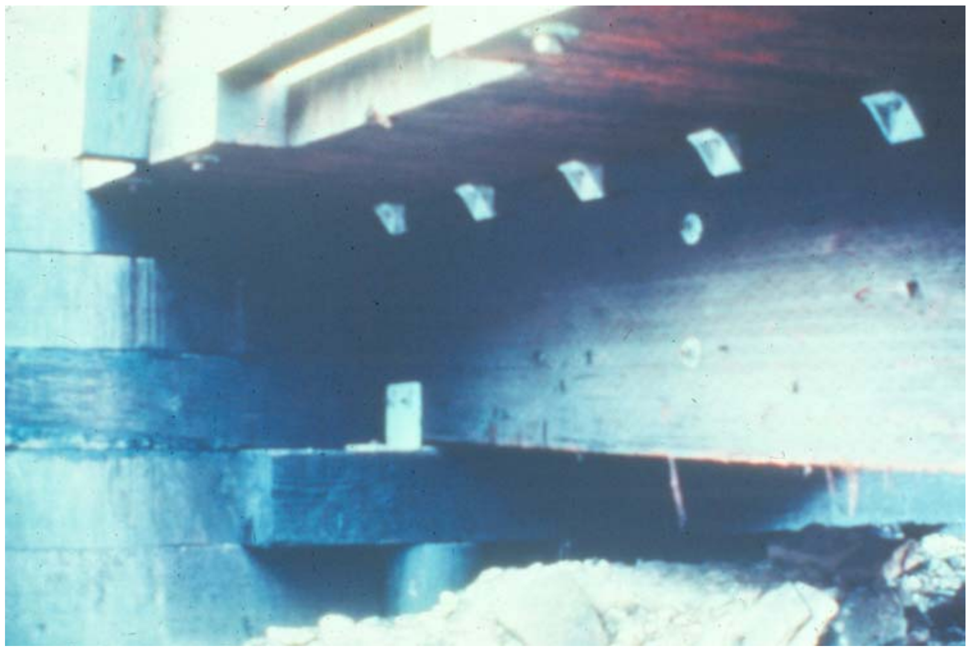

Figure 6.2.12 Bearing Area of Typical Glulam Beam

Shear Zones

Examine for horizontal shear cracks and delaminations near the ends of the beam. Delaminations (i.e., separations in the laminations) can occur due to either failure of the glue or failure at the bond between the glue and the lamination (see Figure 6.2.13). Delaminations that extend completely through the cross section of the member are the most serious since this makes the member act as two smaller members. Delaminations that are located near the center of the cross section are more serious than those that are not. Delaminations directly through a connector are also undesirable.

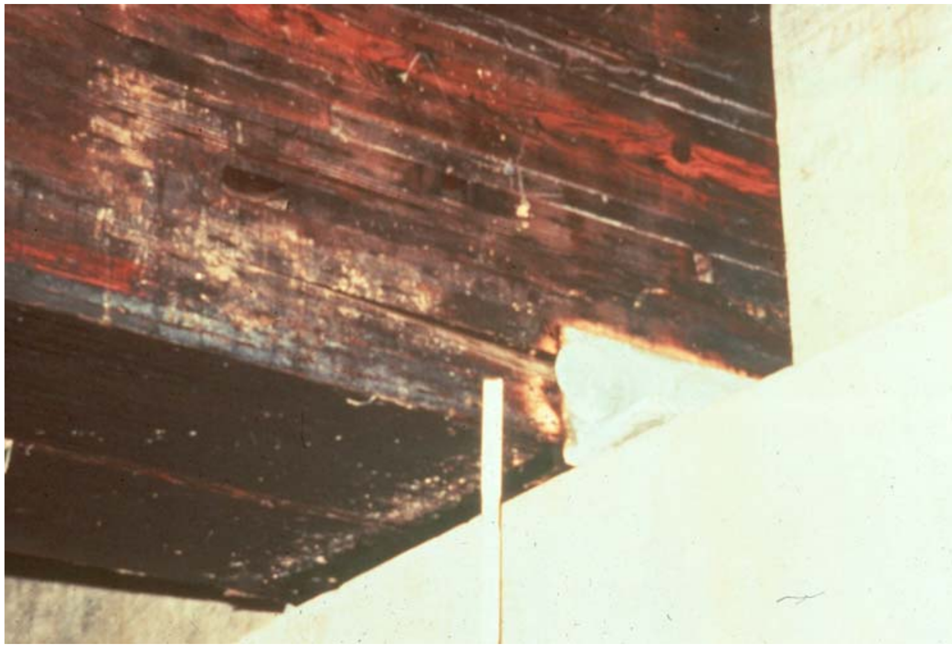

Figure 6.2.13 Close-up View of End of Glulam Bridge Showing Laminations

Tension Zones

Examine the zone of maximum tension for signs of structural distress (see Figure 6.2.14). The maximum tension generally occurs at the bottom half of the middle third of the beam span. Investigate for section loss due to decay or fire, especially near mid-span and at the ends. Inspect for excessive deflection or sagging in the beams.

Figure 6.2.14 Elevation View of Beam of Glulam Multi-beam Bridge

Areas Exposed to Drainage

Investigate for signs of decay along the full length of the member but especially where the beam is subjected to continual wetness or prolonged exposure to moisture (see Figure 6.2.15). Decay and chemical attack may be evidenced by discolored wood, brown and white rot, the formation of fruiting bodies (the result of fungal attacks, which produce disc-shaped bodies that distribute reproductive spores), "sunken" faces in the wood, or the soft “punky” texture of the wood.

Figure 6.2.15 Decay on Glulam Beam

Areas of Insect Infestation

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Further probing or drilling should be performed in suspect areas.

Areas Exposed to Traffic

Check beams in overhead structures for collision damage from vehicles passing below.

Previous Repairs

Thoroughly examine any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

Secondary Members

Examine solid sawn or glulam diaphragms for decay, fire damage, and insect damage (see Figure 6.2.16). Check steel cross bracing for corrosion, bowing, or buckling (see Figure 6.2.17). Examine connections for tightness, cracks and splits, and corroded, loose, or missing fasteners.

Figure 6.2.16 Typical Diaphragm for a Glulam Multi-beam Bridge

Fasteners and connectors

Inspect all fasteners for corrosion, tightness, and missing parts (see Figure 6.2.17).

Figure 6.2.17 Glulam Beams with Numerous Fastener Locations

6.2.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of timber bridges. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBIS rating guidelines.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the superstructure. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Smart Flags are also used to describe the condition of timber bridges.

In an element level condition state assessment of a glulam timber bridge, the AASHTO CoRe elements are:

Element No.	Description
111	Open Girder/Beam
117	Stringer
135	Truss/Arch
156	Floorbeam

The unit quantity for the timber superstructures is in meters or feet, and the total length must be placed in one of the available condition states. Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.

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Section 6

Inspection and Evaluation of Common Timber Superstructures

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Topic 6.3 Stress-Laminated Timber Bridges

6.3.1 Introduction

Stress-laminated timber bridges were first developed in Canada, in 1976, by the Ontario Ministry of Transportation and Communications. These bridges consist of multiple planks mechanically clamped together using metal rods to perform as one unit (see Figure 6.3.1). The compression induced frictional resistance within the timber laminations is the mechanism that makes this structural system effective.

Figure 6.3.1 Stressed-Laminated Timber Deck Bridge Carrying a 90,000-Pound Logging Truck (Source: Barry Dickson, West Virginia University)

6.3.2 Design Characteristics

Stress-Laminated Timber Deck/Slab Bridges

Sawn lumber stress-laminated deck bridges can be used for simple spans of up to 15 m (50 feet) and are capable of carrying modern highway loadings (see Figures 6.3.1 and 6.3.3). Stressed deck bridges have also been constructed using glulam members. Combining glulam technology with stress-lamination increases practical span lengths to 19 m (63 feet) (see Figure 6.3.4).

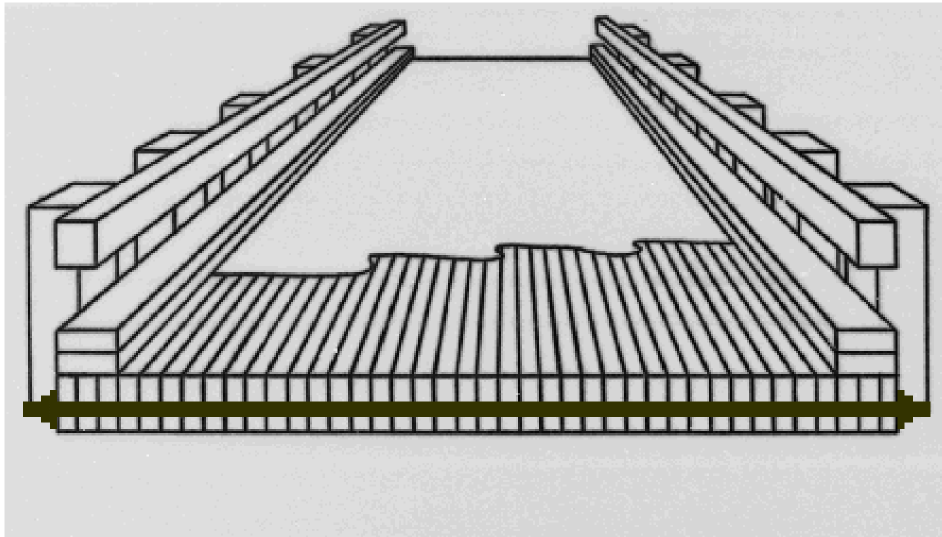

Figure 6.3.2 Typical Section of a Stress-Laminated Timber Deck Bridge

Figure 6.3.3 Solid Sawn Stress-Laminated Deck/Slab Bridge

Figure 6.3.4 Glulam Stress-Laminated Deck/Slab Bridge

Stress-Laminated Timber Tee Beam Bridges

The idea for stress-laminated timber tee beam bridges was developed at West Virginia University. These bridges consist of a stress-laminated deck and glulam beams (see Figure 6.3.6). High strength steel rods are used to join the stress-laminated deck and glulam beams together to form stress-laminated timber tee beams. The first structure of this type was built in 1988, near Charleston, West Virginia. It is about 23 m (75 feet) long and has stressing rods spaced at two feet. It has performed well so far, and stressed tee beams will likely be used in the future to achieve even longer span lengths (see Figure 6.3.7).

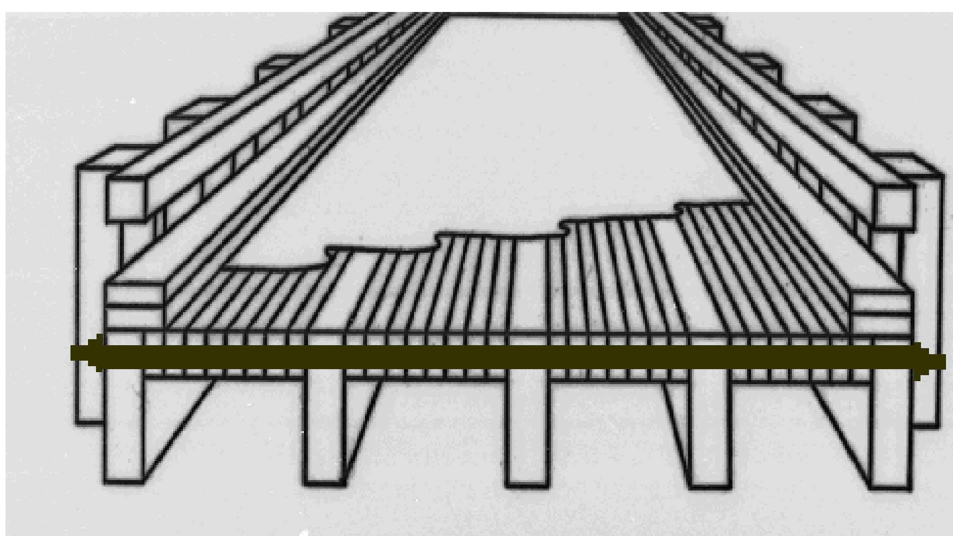

Figure 6.3.5 Typical Section of a Stress-Laminated Timber Tee Beam Bridge (Source: Barry Dickson, West Virginia University)

Figure 6.3.6 Elevation View of Stress-Laminated Timber Tee Beam Bridge (West Virginia)

Stress-Laminated Timber Box Beam Bridges

Stress-laminated timber box beam bridges represent further development of timber bridges by West Virginia University. These bridges consist of adjacent box beam panels individually comprised of stress-laminated flanges and glulam beam webs (see Figure 6.3.8). This bridge type is also known as a cellular stressed deck. Span lengths of up to 18 m (60 feet) have been designed, and there is a potential for longer spans (see Figure 6.3.9).

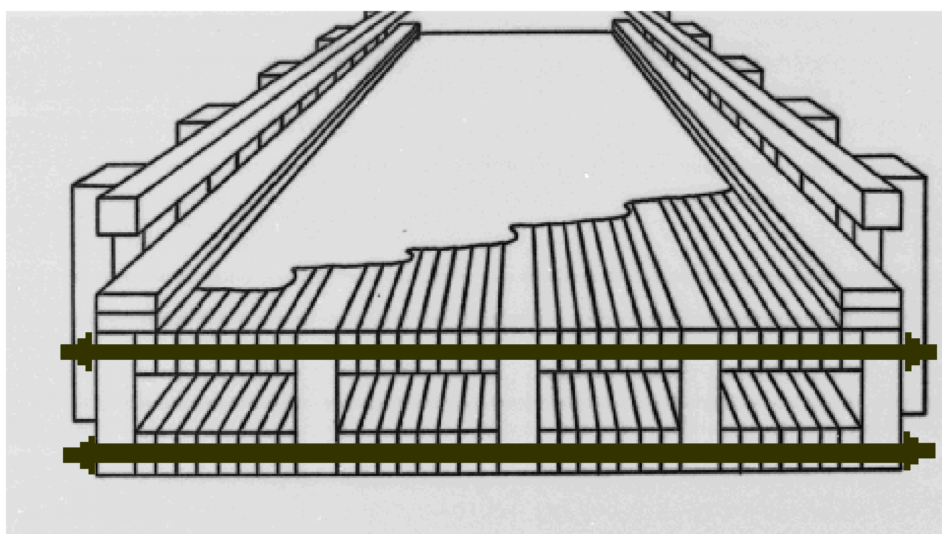

Figure 6.3.7 Typical Section of a Stress-Laminated Timber Box Beam (Source: Barry Dickson, West Virginia University)

Figure 6.3.8 Stress-Laminated Timber Box Beam Bridge Being Erected

Stress-Laminated Timber K-frame Bridges

Stressed K-frame bridges represent further development of the stressed deck bridge by the Ontario Ministry of Transportation and Communications. These bridges consist of three spans in which the stressed deck is supported at two intermediate points by stressed laminated timber struts (see Figure 6.3.5). This bridge type has been used for a bridge with a total length of 13 m (43 feet), and it has a potential for span lengths over 15 m (50 feet).

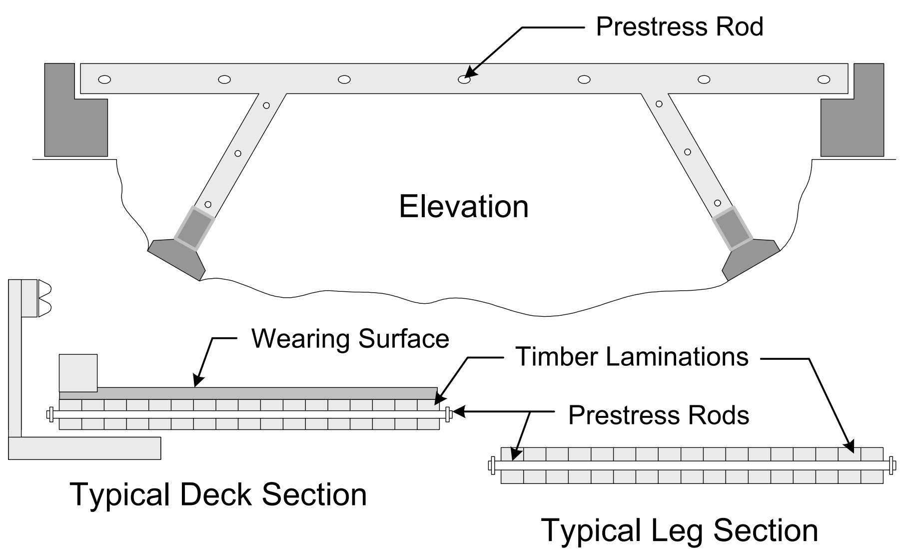

Figure 6.3.9 Stress-Laminated Timber K-frame Bridge

Primary and Secondary Members

The primary members are the decks, tee beams, and box beams. The secondary members are the diaphragms and cross bracing between beams.

6.3.3 Overview of Common Defects

Common defects that occur on stressed timber bridges include:

- Checks, splits, and shakes
- Decay by fungi
- Damage by insects and borers
- Damage from impact/collisions
- Damage from abrasion/wear
- Damage from weathering/warping
- Damage from overstress

Other less common defects that may be encountered by the inspector include damage from chemical attack and damage from fire, which can be very destructive to timber structures. Refer to Topic 2.1 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

6.3.4 Inspection Procedures and Locations

The inspection locations and procedures for stressed timber bridges are similar to those for glulam bridges.

Procedures

Advanced Inspection Techniques

In addition, several advanced techniques are available for timber inspection. Nondestructive methods, described in Topic 13.1.2, include:

- Pol-Tek
- Spectral analysis
- Ultrasonic testing
- Vibration

Other methods, described in Topic 13.1.3, include:

- Boring or drilling
- Moisture content
- Probing
- Shigometer

Locations

Stressing Rods

Examine the condition of the steel stressing rods, and inspect for crush and splits in the fascia members. Check for loss of prestress in the rods, which would be indicated by shifted planks in the stress-laminated timber element and excessive deflection. This may be observed when the bridge is subject to a moving live load.

Figure 6.3.10 Broken Stressing Rods

Bearing Areas

Inspect the bearing areas for crushing of the beams. Investigate for decay and insect damage by visual inspection, sounding, and/or probing at the ends of the beams. Also check the condition and operation of the bearing devices if they are present (refer to Topic 9.1, Bearings).

Shear Zones

Examine for horizontal shear cracks and delaminations near the ends of the beam. Delaminations (i.e., separations in the laminations) can occur due to either failure of the glue or failure at the bond between the glue and the lamination (see Figure 6.3.11). Delaminations that extend completely through the cross section of the member are the most serious since this makes the member act as two smaller members.

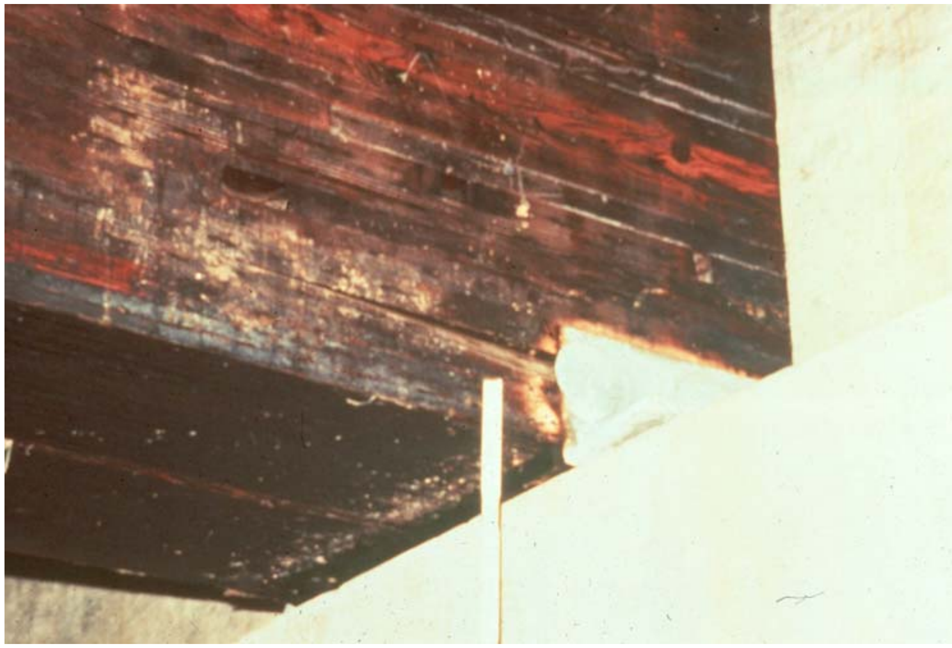

Figure 6.3.11 Close-up View of End of a Stressed Timber Bridge Showing Laminations

Tension Zones

Examine the zone of maximum tension for signs of structural distress. The maximum tension generally occurs at the bottom half of the middle third of the beam span. Investigate for section loss due to decay or fire, especially near mid-span and at the ends. Inspect for excessive deflection or sagging in the beams.

Areas Exposed to Drainage

Investigate for signs of decay along the full length of the member but especially where the beam is subjected to continual wetness or prolonged exposure to moisture. Decay and chemical attack may be evidenced by discolored wood, brown and white rot, the formation of fruiting bodies (the result of fungal attacks, which produce disc-shaped bodies that distribute reproductive spores), "sunken" faces in the wood, or the soft “punky” texture of the wood.

Areas of Insect Infestation

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Further probing or drilling should be performed in suspect areas.

Areas Exposed to Traffic

Check beams in overhead structures for collision damage from vehicles passing below.

Previous Repairs

Thoroughly examine any repairs that have been previously made. Determine if repaired areas are sound and functioning properly.

Secondary Members

Examine solid sawn or glulam diaphragms for decay, fire damage, and insect damage. Check steel cross bracing for corrosion, bowing, or buckling. Examine connections for tightness, cracks and splits, and corroded, loose, or missing fasteners.

Fasteners and Connectors

Inspect all fasteners for corrosion, tightness, and missing parts. Stressing rod hardware is the most important fastener system on a stress-laminated timber bridge.

Further development of the stressed timber bridge concept is being performed at the University of Wisconsin, West Virginia University, and Pennsylvania State University, as well as in Canada.

6.3.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of timber bridges. The two major rating guideline systems currently in use are the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0, where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBIS rating guidelines.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the superstructure. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Pontis Smart Flags are also used to describe the condition of timber bridges.

In an element level condition state assessment of timber bridges, the AASHTO CoRe elements are:

Element No.	Description
11	Timber Deck - Bare
12	Timber Deck with A/C Overlay
54	Timber Slab - Bare
55	Timber Slab with A/C Overlay
111	Open Girder/Beam

The unit quantity for the timber superstructures is in meters (or feet), and the total length must be placed in one of the four available condition states. The unit quantity of decks and slabs is "each", and the entire element must be placed in one of the five available condition states. Some states have elected to use the total square area (m^2 or ft^2). Condition state 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned.